DESIGN AND ANALYSIS OF LEAF SPRING
BY USING COMPOSITE MATERIAL FOR
LIGHT VEHICLES

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ABSTRACT

Reducing weight while increasing or maintaining strength of products is getting to be highly important research issue in this modern world. Composite materials are one of the material families which are attracting researchers and being solutions of such issue. In this paper we describe design and analysis of composite leaf spring. For this purpose, a rear leaf spring for MAHINDRA “MODEL-COMMANDER 650 DI” is considered.

The objective is to compare the stresses, deformations and weight saving of composite leaf spring with that of steel leaf spring. The design constraint is stiffness. The Automobile Industry has great interest for replacement of steel leaf spring with that of composite leaf spring, since the composite materials has high strength to weight ratio, good corrosion resistance.

The material selected was glass fiber reinforced polymer (E-glass/epoxy) is used against conventional steel. The design parameters were selected and analyzed with the objective of minimizing weight of the composite leaf spring as compared to the steel leaf spring.

Result shows that, the weight of composite leaf spring was nearly reduced up to 85% compared with steel material. The leaf spring was modeled in Pro/ENGINEER and the analysis was done using ANSYS 12.0 software. The fatigue life of both steel and composite leaf is compared using ANSYS software.

Key words: Stiffness, Composite Leaf Spring, E-Glass/Epoxy, ANSYS 12.0, Pro/ENGINEER.


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1. INTRODUCTION

1.1. Leaf Springs

Originally called laminated or carriage spring, a leaf spring is a simple form of spring, commonly used for the suspension in wheeled vehicles. It is also one of the oldest forms of springing, dating back to medieval times.

The advantage of leaf spring over helical spring is that the end of the springs may be guided along a definite path.

Sometimes referred to as a semi-elliptical spring or cart spring, it takes the form of a slender arc-shaped length of spring steel of rectangular cross-section. The center of the arc provides location for the axle, while tie holes are provided at either end for attaching to the vehicle body. For very heavy vehicles, a leaf spring can be made from several leaves stacked on top of each other in several layers, often with progressively shorter leaves. Leaf springs can serve locating and to some extent damping as well as springing functions. While the interleaf friction provides a damping action, it is not well controlled and results in stiction in the motion of the suspension. For this reason manufacturers have experimented with mono-leaf springs.

A leaf spring can either be attached directly to the frame at both ends or attached directly at one end, usually the front, with the other end attached through a shackle, a short swinging arm. The shackle takes up the tendency of the leaf spring to elongate when compressed and thus makes for softer springiness. Some springs terminated in a concave end, called a spoon end (seldom used now), to carry a swivelling member.

There were a variety of leaf springs, usually employing the word "elliptical". "Elliptical" or "full elliptical" leaf springs referred to two circular arcs linked at their tips. This was joined to the frame at the top center of the upper arc, the bottom center was joined to the "live" suspension components, such as a solid front axle. Additional suspension components, such as trailing arms, would be needed for this design, but not for "semi-elliptical" leaf springs as used in the Hotchkiss drive. That employed the lower arc, hence its name. "Quarter-elliptic" springs often had the thickest part of the stack of leaves stuck into the rear end of the side pieces of a short ladder frame, with the free end attached to the differential, as in the Austin Seven of the 1920s. As an example of non-elliptic leaf springs, the Ford Model T had multiple leaf springs over its differential that was curved in the shape of a yoke. As a substitute for dampers (shock absorbers), some manufacturers laid non-metallic sheets in between the metal leaves, such as wood.

Leaf springs were very common on automobiles, right up to the 1970s in Europe and Japan and late 70's in America when the move to front wheel drive, and more sophisticated suspension designs saw automobile manufacturers use coil springs instead. Today leaf springs are still used in heavy commercial vehicles such as vans and trucks, SUVs, and railway carriages. For heavy vehicles, they have the advantage of spreading the load more widely over the vehicle's chassis, whereas coil springs transfer it to a single point. Unlike coil springs, leaf springs also locate the rear axle, eliminating the need for trailing arms and a Pan hard rod, thereby saving cost and weight in a simple live axle rear suspension.

A more modern implementation is the parabolic leaf spring. This design is characterised by fewer leaves whose thickness varies from centre to ends following a parabolic curve. In this design, inter-leaf friction is unwanted, and therefore there is only contact between the springs at the ends and at the centre where the axle is
connected. Spacers prevent contact at other points. Aside from a weight saving, the main advantage of parabolic springs is their greater flexibility, which translates into vehicle ride quality that approaches that of coil springs. There is a trade-off in the form of reduced load carrying capability, however. The characteristic of parabolic springs is better riding comfort and not as "stiff" as conventional "multi-leaf springs". It is widely used on buses for better comfort. A further development by the British GKN company and by Chevrolet with the Corvette amongst others, is the move to composite plastic leaf springs.

Typically when used in automobile suspension the leaf both supports an axle and locates/partially locates the axle. This can lead to handling issues (such as 'axle tramp'), as the flexible nature of the spring makes precise control of the unsprung mass of the axle difficult. Some suspension designs which use leaf springs do not use the leaf to locate the axle and do not have this drawback. The Fiat 128's rear suspension is an example.

![Figure 1 A traditional leaf spring arrangement.](image)

A leaf spring is a long, flat, thin, and flexible piece of spring steel or composite material that resists bending. The basic principles of leaf spring design and assembly are relatively simple, and leafs have been used in various capacities since medieval times. Most heavy duty vehicles today use two sets of leaf springs per solid axle, mounted perpendicularly to support the weight of the vehicle. This Hotchkiss system requires that each leaf set act as both a spring and a horizontally stable link. Because leaf sets lack rigidity, such a dual-role is only suited for applications where load-bearing capability is more important than precision in suspension response.

1.2. How Leaf Springs Work

Before you start your towing trip, it's a good idea to go over a brief checklist -- for safety's sake. You take a good look in your mirrors, adjusting them correctly in order to see passing traffic on the road. You've chosen the correct hitch and connected the towing vehicle to the trailer properly. The brake lights and braking systems are working synchronously, assuring you of the ride's legality. With everything loaded up, you're pretty confident the truck is ready for the job, so you head out on the road toward your destination. Once you reach a steady speed, however, the trailer behind your truck starts to bounce and sway a little more than it should. Pulling over to the side of the road, you rack your brains to figure out what you missed. You start to wonder if your cargo weight is maybe too high -- but what can you do about it?

In this situation, if there's too much cargo weighing down a towed vehicle, causing everything to rock and sway, the issue may be with the suspension. If a
truck's suspension is too rigid, its wheels will often leave the pavement after hitting bumps; a good suspension, on the other hand, keeps the wheels on the ground as much as possible. Many towers use leaf springs to stabilize their towed load and to keep their cargo grounded.

Although you may not ever have heard about or even noticed leaf springs on larger tow vehicles, the technology has been around for centuries and is one of the earliest forms of suspension. Even Leonardo da Vinci used leaf springs in his diagram for a self-propelled car. But how do they work? Are there different types of leaf springs? And how do you install them onto a vehicle?

1.3. Overview of Leaf Spring

1.3.1. Introduction

Semi-elliptic leaf springs are almost universally used for suspension in light and heavy commercial vehicles. For cars also, these are widely used in rear suspension.

The spring consists of a number of leaves called blades. The blades are varying in length. The blades are us usually given an initial curvature or cambered so that they will tend to straighten under the load. The leaf spring is based upon the theory of a beam of uniform strength. The lengthiest blade has eyes on its ends. This blade is called main or master leaf, the remaining blades are called graduated leaves. All the blades are bound together by means of steel straps.

The spring is mounted on the axle of the vehicle. The entire vehicle load is rests on the leaf spring. The front end of the spring is connected to the frame with a simple pin joint, while the rear end of the spring is connected with a shackle. Shackle is the flexible link which connects between leaf spring rear eye and frame. When the vehicle comes across a projection on the road surface, the wheel moves up, this leads to deflecting the spring. This changes the length between the spring eyes.

1.3.2. Suspension System

The automobile chassis is mounted on the axles, not direct but some form of springs. This is done to isolate the vehicle body from the road shocks, which may be in the form of bounce, pitch, roll or sway. These tendencies give rise to an uncomfortable ride and also cause additional stress in the automobile frame anybody. All the part, which performs the function of isolating the automobile from the road shocks, is collectively called a suspension system. It includes the springing device used and various mountings for the same.

Broadly speaking, suspension system consists of a spring and a damper. The energy of road shock causes the spring to oscillate. These oscillations are restricted to a reasonable level by the damper which is more commonly called a shock absorber.

1.3.2.1. Objective of Suspension

1. To prevent the road shocks from being transmitted to the vehicle components.
2. To safeguard the occupants from road shocks
3. To preserve the stability of the vehicle in pitting or rolling, while in motion

1.3.2.2. Basic Considerations for vertical loading

When the rear wheel comes across a bump or pit on the road, it is subjected to vertical forces, tensile or compressive depending upon the nature of the road irregularity. These are absorbed by the elastic compression, shear, bending or twisting of the
spring. The mode of spring resistance depends upon the type and material of the spring used.

Further when the front wheel strikes a bump it starts vibrating. These vibrations die down exponentially due to damping present in the system. The rear wheel however, reaches the same bump after certain time depending on the wheel base and the speed of the vehicle. Of course, when the rear wheel reaches the bump, it experiences similar vibrations as experienced by the front wheel some time ago. It is seen that to reduce pitching tendency of the vehicle, the frequency of the front springing system be less than that of the rear springing system.

From human comfort point also it is seen that it is desirable to have low vibration frequencies. The results of the studies of human beings have shown that the maximum amplitude which may be allowed for a certain level of discomfort decreases with the increase of vibration frequency.

1.3.2.3. Rolling
The centre of gravity of the vehicle is considerably above the ground. Due to this reason, while taking a turn, the centrifugal force acts outwards on the C.G of the vehicle, while the road resistance acts inward at the wheels. This gives rise to a couple turning the vehicle about a longitudinal axis. This is called rolling. The manner in which the vehicle is sprung determines the axis about which the vehicle will roll. The tendency to roll is checked by means of a stabilizer.

1.3.2.4. Brake-dip
On braking, the noise of the vehicle has a tendency to be lowered or to dip. This depends upon the position of centre of gravity relative to the ground, the wheelbase, and other suspension. In the characteristics the same way, torque loads during acceleration end the front of the vehicle to be lifted. These forces on account of braking and driving are carried directly by deflecting the springs, by wishbone arms or by radius rods.

1.3.2.1. Side Thrust
Centrifugal force during cornering, cross-winds, cambering of the road etc, cause a side-thrust to be applied to the vehicle, such forces are usually absorbed by the rigidity of the leaf springs or by fitting pan hard rods.

1.3.2.1. Unsprung Weight:
Un-sprung weight is the weight of vehicle components between the suspension and then road surface. This includes rear axle assembly, steering knuckle, and front axle in case of rear drive rigid suspension, wheels, tires and brakes. The sprung weight i.e. the weight supported by the vehicle suspension system, includes the frame, body, engine, and the entire transmission system.

When the wheels strike against a bump, they vibrate along with other unsprung parts which store the energy of the vibrations and then further transmit it to the sprung parts via the springs. Thus it is seen that greater the weight of the unsprung parts, greater will be the energy stored due to vibrations and consequently greater shocks.

When a small shock results in the large movements of the wheel, the suspension is said to be soft, such a soft suspension is more comfortable to the occupants. However, excessively soft suspension will result in the loss of braking efforts are decreased.
Thus a good suspension system should be an optimum compromise between softness and hardness.

1.3.2.5. Function of suspension springs
Springs are placed between the road wheels and the body. When the wheel comes across a bump on the road, it rises and deflects the spring, thereby storing energy there in. On releasing due to the elasticity of the spring materials, it rebounds thereby expending the stored energy. In this way the spring starts vibrating, with amplitude decreasing gradually on account of internal friction of the spring material and friction of the suspension joints, till vibrations die down.

1.3.2.6. Types of Suspension systems

Plastic Suspension
Viberitis. P.A of TURINE has developed a new type of suspension based upon the use of resilient plastic rings in compression. The suspension consists of a cylindrical container secured to the chassis, a shaft attached to the axle and free to slide within the plastic rings contained in the cylinder, there are two centering rings, the bottom one fixed to the lower end of the cylinder and the upper one is arranged as high as possible keeping in consideration that in the rebound position shaft must remain supported by it by the plastic rings and absorb the vertical dynamic load.

Independent Suspension
When a vehicle with rigid axle suspension encounters road irregularities the axle tilts and the wheels no longer remain vertical. This causes the whole of the vehicle to tilt on one side. Such a state of affairs is not desirable. Apart from causing rough ride, it causes ‘wheel wobble’. The road adhesion is also decreased. To avoid this, the wheels are sprung independent of each other, so that tilting of one does not affect the other. Besides the independent suspension also have the following advantages over rigid type suspension.

1. The elastic strain energy per unit spring weight stored in a coil or torsion bar is greater than in case of a semi-elliptical leaf spring, which means lighter springs can be used in case of independent suspension.
2. In case of independent suspension, unsprung weight is reduced, which ultimately reduced the tyre scrub and hence increase tyre lift
3. Compared to the rigid axle, type, softer springs can be used without increasing rolling effect. Soft springs improve ride comfort.
4. When anti-roll bar is used in independent suspension, springs employed may be even softer, in the event of vertical cornering, the anti-roll bar will provide the forces necessary to resist body roll.
5. In case of independent suspension it is possible to locate the springs apart enough obtain under-see condition.
6. With independent suspension, steering geometry is not altered with spring deflection as in case of conventional rigid axle suspension where effect is especially noticeable during breaking or acceleration.
7. In this case the engine and the chassis frame can be placed relatively lower which means engine position can be moved forward resulting in more space for passengers.
Front Wheel Independent Suspension

Independent suspension has become almost universal in the case of front axle, due to the simplicity of such a suspension system.

Rear Wheel Independent Suspension:

Though the rear wheels are not to be steered, yet there is a considerable difficulty in the rear wheel springing if the power has to be transmitted to the rear wheel. But even the rear wheel independent springing is coming into prominence because of its distinct advantages over the rigid axle type.

Universal couplings keep the wheel vertical, while the sliding coupling is required to maintain the wheel track constant, thereby avoiding scrubbing of the tyres: this method has been used in the DEDION type of axle.

Another method of rear wheel independent suspension is the trailing link type. In this the trailing links are pivoted at right angles to the longitudinal axis of the car and carry the rear wheels at their ends. The trailing links hold the wheels firmly and also sustain accelerating the braking force.

It is claimed that the combined metal – rubber mountings respond softly on straight roads, increasing ride comfort. When cornering, they resist lateral force with a reliable stabilizing effect, even when the car is fully loaded.

Apart from the distinct advantages, which the independent suspension possesses, it has its own drawbacks also:

1. The initial cost is high
2. Greater maintenance required because of larger number of bearings.
3. Misalignment of steering geometry with the wear of components. Thus requires more attention.
4. In the event of body roll, the wheels camber (tilt outwards in case of wishbone type), due to which cornering power is reduced.
5. More rigid sub-frame or chassis frame required.
6. Forces due to unbalanced wheels are more pronounced and transmitted easily to the steering wheel.

Wishbone type suspension:

The use of coil springs in the front axle suspension of car is now almost universal. It consists of upper and the lower wishbone arms pivot to the frame member. The spring is placed in between the lower wishbone and the underside of the cross member. The vehicle weight is transmitted from the body and the cross member to the coil spring through which it goes to the lower wishbone member. A shock absorber is placed inside the coil spring and is attached to the cross member and the lower wishbone member. The wishbone type is the most popular independent suspension system.

Mac Pherson Strut Type of Suspension:

In this layout only lower wishbone are used. A strut containing shock absorbing and the spring carriers also the stub axle on which the wheel is mounted. The wishbone is hinged to the cross member and positions the wheel as well as resists accelerating, braking and side forces. This system is simpler than double wishbone type described above and is also lighter, keeping the unsprung weight lower. This type of suspension gives the maximum room in the engine compartment and is, therefore commonly used.
Design and Analysis of Leaf Spring by Using Composite Material For Light Vehicles

on front wheel drive cars. In India this system has been used in Maruti (Suzuki) 800 cars. This type of suspension with anti-roll bar as employed in Volkswagen Jetta and Passat cars. This is claimed to provide increased road safety, improve ride comfort and light and self-stabilizing steering which means that car continues along its chosen line of travel when the brakes are applied even though the road surface may vary.

**Vertical guide suspension**

The king pin is attached directly to the cross member of the frame. It can slide up and down, corresponding to the up and down motions of the wheel, thus compressing or elongating the springs. In this the track, wheel base and wheel attitude remain unchanged, but the system is having disadvantages of decreased stability.

**Trailing Link Suspension**

In this type of suspension, a coil spring is attached to the trailing link which itself is attached to the carrying the wheel hub. When the wheel moves up and down, it winds and unwinds the spring. A torsion bar has also been used in certain designs in place of the coil spring. The system does maintain the camber and the wheel track constant. However, the distance between the front and the rear wheels does change. Difficulty to remedy this defect is the main reason for its very limited use in actual practice.

**Winging Half Axle Suspension**

In this wheels are mounted rigidly on the half axles, which are pivoted on their ends to the chassis member at the middle of car. The main disadvantage of this system is that up and down movement of the wheel causes the camber angle to vary.

**Interconnected Suspension Systems:**

In these systems, the front and rear suspension units or else the units on the two sides of the automobile are connected together. These are also called ‘linked system’. The major advantage of such a system is that tendency of the vehicle to bounce, pitch or roll is reduced and a constant desirable attitude of suspension. The other systems in current use are the Hydro elastic suspension, the Daimler – Benz suspension and the Hydra gas suspension system.

**Air Suspension**

Air suspension systems are coming into prominence because of certain advantages they possess over the conventional metal springs. The advantages are:

1. A vehicle space for wheel deflection is put to optimum use by virtue if the automatic control devices.
2. Because of the vehicle is also constant, changes in headlamp alignment due to varying loads are avoided.
3. The spring rare varies much less between the laden and unladen conditions, as compared with that of conventional steel springs. This reduces the dynamic loading.
4. The improved standard for ride comfort and noise reduction with air springs reduces both driver and passenger fatigue.

The four air springs, which may be either the bellows type or the piston type, are mounted in the same position where generally the coil springs are mounted. An air compressor takes the atmospheric air through a filter and compresses it to a pressure of 240 MPa, at which pressure of air in the accumulator tank is maintained, which is also provided with a safety relief. The high pressure air goes through lift control valve
and the levelling valves, to the air springs. The control valve is operated manually by means of a handle on the control panel, through a cable running from the valve to the handle.

**Hydro elastic Suspension**

In this system a displacer unit is fitted at each of the four wheels. The displacer units are all interconnected by means of fluid. In the displacer unit, rubber (under compression and shear) is used as a spring where as fluid rubber pressure acts as damping medium. The stem is connected to the wheel through suitable linkage so that its movement is proportional to the up and down movement of the wheel. A two way valve assembly controls the up and down flow of the fluid. The upper valve opens when the fluid pressure below rises sufficiently.

2. CONCEPT OF FATIGUE

2.1. Fatigue

In narrow sense, the term fatigue of materials and structural components means damage and damage due to cyclic, repeatedly applied stresses. In a wide sense, it includes a large number of phenomena of delayed damage and fracture under loads and environmental conditions. It is expedient to distinguish between high-cycle (classic) and low-cycle fatigue.

Plastic deformations are small and localized in the vicinity of the crack tip while the main part of the body is deformed elastically, then one has high-cycle fatigue. If the cyclic loading is accompanied by plastic deformation in the bulk of the body, then one has a low-cycle fatigue. Usually we say low-cycle fatigue if the cycle number up to the initiation of a visible crack or until final fracture is below 104 or 5.104 cycles.

In material science, fatigue is the progressive, localized, and permanent structural damage that occurs when a material is subjected to cyclic or fluctuating strains at nominal stresses that have maximum values less than (often much less than) the static yield strength of the material. The resulting stress may be below the ultimate tensile stress, or even the yield stress of the material, yet still cause catastrophic failure. A practical example of low-cycle fatigue would be the bending of a paperclip. A metal paperclip can be bent past its yield point without breaking, but repeated bending in the same section of wire will cause material to fail.

2.2. Fatigue Strength

Fatigue strength is defined as the maximum stress that can be endured for a specified number of cycles without failure. Low cycle fatigue strength approaches the static strength. When the cycle number exceeds to one limit, the fatigue strength falls to fraction of the static strength.

The fatigue strength is the value of the alternating stress that results in failure by fracture a specific number of cycles of load application. It can also be the ordinate of the σ-n (stress versus number of cycles to failure) curve.

The fatigue behaviour of a specific material, heat treated to a specific strength level is determined by a series of laboratory tests on a large number of apparently identical samples of those specific materials.

The specimens are machined with shape characteristics which maximize the fatigue life of a metal, and are highly polished to provide the surface characteristics
which enable the best fatigue life. A single test consist of applying a known, constant bending stress to a round sample of the material, and rotating the sample around the bending stress axis until it fails. As the sample rotates, the stress applied to any fiber on the outside surface of the sample varies from maximum-tensile to zero to maximum compressive and back. The test mechanism counts the number of rotations (cycles) until the specimen fails. A large number of tests is run at each stress level of interest, and the results are statistically massaged to determine the expected number of cycles to failure at that stress level.

The cyclic stress level of the first set of tests is some large percentage of the Ultimate Tensile stress (UTS), which produces failure in a relatively small number of cycles. Subsequent tests are run at lower cyclic stress values until a level is found at which the sample will survive 10 million cycles without failure. The cyclic stress level that the material can sustain for 10 million cycles is called the Endurance (EL).

2.3. Fatigue Failure

Failure is one of most important aspects of material behaviour because it is directly influent the selection of material for certain application, the method of manufacturing and service life of component. The majority of engineering failures are caused by fatigue. Fatigue failure is defined as the tendency of a material to fracture by means of progressive brittle cracking under repeated alternating or cyclic stresses of intensity considerably below the normal strength. Although the fracture is of a brittle type, it may take some time to propagate, depending on both the intensity and frequency of the stress cycles. Nevertheless, there is very little, if any, warning below failure if the crack is not noticed. The number of cycles required to cause fatigue failure at a particular peak stress is generally quiet large, but it decreases as the stress is increased. For some mild steels, cyclical stresses can be continued indefinitely provided the peak stress (sometimes called fatigue strength) is below the endurance limit value.

A good example of fatigue failure is breaking a thin steel rod or wire with your hands after bending it back and forth several times in the same place. Another example is an unbalanced pump impeller resulting in vibrations that can cause fatigue failure.

The type of fatigue of most concern in circuit cards, gasoline, diesel, gas turbine engines and many industrial applications is thermal fatigue. Thermal fatigue can arise from thermal stresses produced by cyclic changes in temperature. Fundamental requirements during design and manufacturing for avoiding fatigue failure are different for different cases and should be considered during design phase.

Fatigue failures almost always begin at the surface of a material. The reasons are:

1. The most highly-stresses fibers are located at the surface (bending fatigue)
2. The inter granular flaws which precipitate tension failure are most frequently found at the surface.

Suppose that a particular specimen is being fatigue tested. Now suppose the fatigue test is halted after 20% to 25% of the expected life of the specimen, and the surface condition is restored to its original state. Now the fatigue test is resumed at the same stress level as before. The life of the part will be considerably longer than expected. If that process is repeated several times, the life of the part may be extended by several hundred percent, limited only by the available cross section of the specimen. That proves fatigue failures originate at the surface of a component.
Fatigue failure is also due to crack formation and propagation. A fatigue crack will typically initiate at a discontinuity in the material where the cyclic stress is a maximum. Discontinuities can arise because of:

1. Design of rapid changes in cross-section, keyways, holes, etc. where the cyclic stress concentrations occur.
2. Element that roll and/or slide each other (bearings, gears, cams) under high contact pressure, developing concentrated subsurface contact surfaces that can cause pitting from after many cycles of the load.
3. Carelessness in locations of stamp marks, tool marks, scratches, and burrs; poor joint design; improper assembly; and other fabrications faults.
4. Compositions of the material itself as processed by rolling, forging, casting, extrusion, drawing and heat treatment. Microscopic and sub-microscopic surface and subsurface discontinuities arise. Fatigue fracture typically occurs in material of basically brittle nature. External or internal cracks develop at pre-existing flaws or fault of defects in the material; these cracks then propagate and eventually they lead to total failure of part. The fracture surface in fatigue is generally characterized by the term “beach marks.”

2.4. Materials for Leaf Spring

The material used for leaf springs is usually a plain carbon steel having 0.90 to 1.0% carbon. The leaves are heat treated after the forming process. The heat treatment of spring steel products has greater strength and therefore greater load capacity, greater range of deflection and better fatigue properties [14].

2.4.1. Carbon/Graphite fibers

Their advantages include high specific strength and modulus, low coefficient of thermal expansion and high fatigue strength. Graphite, when used alone has low impact resistance. Its drawbacks include high cost, low impact resistance and high electrical conductivity [14].

2.4.2 Glass fibers

The main advantage of Glass fiber over others is its low cost. It has high strength, high chemical resistance and good insulating properties. The disadvantages are low elastic modulus poor adhesion to polymers, low fatigue strength and high density, which increase leaf spring weight and size. Also crack detection becomes difficult [14].

2.4.3 Composite materials

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other.

2.4.4 Natural composites

Natural composites exist in both animals and plants. Wood is a composite – it is made from long cellulose fibres (a polymer) held together by a much weaker substance called lignin. Cellulose is also found in cotton, but without the lignin to bind it together it is much weaker. The two weak substances – lignin and cellulose – together form a much stronger one. The bone in your body is also a composite. It is made from
a hard but brittle material called hydroxyapatite (which is mainly calcium phosphate) and a soft and flexible material called collagen (which is a protein). Collagen is also found in hair and finger nails. On its own it would not be much use in the skeleton but it can combine with hydroxyapatite to give bone the properties that are needed to support the body.

2.4.5 Early composites
People have been making composites for many thousands of years. One early example is mud bricks. Mud can be dried out into a brick shape to give a building material. It is strong if you try to squash it (it has good compressive strength) but it breaks quite easily if you try to bend it (it has poor tensile strength). Straw seems very strong if you try to stretch it, but you can crumple it up easily. By mixing mud and straw together it is possible to make bricks that are resistant to both squeezing and tearing and make excellent building blocks. Another ancient composite is concrete. Concrete is a mix of aggregate (small stones or gravel), cement and sand. It has good compressive strength (it resists squashing). In more recent times it has been found that adding metal rods or wires to the concrete can increase its tensile (bending) strength. Concrete containing such rods or wires is called reinforced concrete.

Making composites
Most composites are made of just two materials. One is the matrix or binder. It surrounds and binds together fibres or fragments of the other material, which is called the reinforcement.

Modern examples
The first modern composite material was E-glass. It is still widely used today for boat hulls, sports equipment, building panels and many car bodies. The matrix is a plastic and the reinforcement is glass that has been made into fine threads and often woven into a sort of cloth. On its own the glass is very strong but brittle and it will break if bent sharply. The plastic matrix holds the glass fibres together and also protects them from damage by sharing out the forces acting on them. Some advanced composites are now made using carbon fibres instead of glass. These materials are lighter and stronger than E-glass but more expensive to produce. They are used in aircraft structures and expensive sports equipment such as golf clubs.

Composite Leaf Springs
Composites are well suited for leaf-spring applications due to their high strength-to-weight ratio, fatigue resistance and natural frequency. Internal damping in the composite material leads to better vibration energy absorption within the material, resulting in reduced transmission of vibration noise to neighboring structures.

The biggest benefit, however, is mass reduction: Composite leaf springs are up to five times more durable than a steel spring, so when General Motors (GM, Detroit, Mich.) switched to a glass-reinforced epoxy composite transverse leaf spring (supplied by Liteflex LLC, Englewood, Colo.) on the 1981 Chevrolet Corvette C4, a mono-leaf composite spring, weighing 8 lb/3.7 kg, replaced a ten-leaf steel system that weighed 41 lb/18.6 kg. This reportedly enabled GM to shave 15 kg/33 lb of unsprung weight from the Corvette, yet maintain the same spring rates. The leaf spring was transverse-mounted; that is, it ran across the car’s width at each axle. This
eliminated the coil springs that sit up high in a spring pocket on the frame. Thus, the car can sit lower to the ground, which improves car handling.

Today, GM continues to employ transverse GFRP composite leaf springs on the front and back of its Corvette models. The 2014 Chevrolet Corvette Coupe includes a double-wishbone suspension, which, at GM, goes by the name short/long arm (SLA). SLA refers to the fact that the upper control arm is shorter than the lower one. A transverse composite leaf spring presses against the lower arm and spans the width of the car. In fact, the spring is always loaded against the sub frame. This design directs shock loads into the frame side, eliminating the standalone rear antiroll bar that must be incorporated into models with standard suspension packages. The spring’s camber curve also is said to improve tire contact with the road during cornering.

Composites also have the potential to replace steel and save weight in longitudinal leaf springs (see “Building a stronger longitudinal leaf spring,” under "Editor's Picks," at top right). These run parallel to the length of the vehicle, providing suspension as an integrated part of the wheel guidance system. “Longitudinal leaf springs have a higher safety factor,” claims Frank Fetscher, head of business development, Benteler-SGL (Ried, Austria), a joint venture of Benteler Automotive and the SGL Group – The Carbon Company (Wiesbaden, Germany, see “SGL Automotive Carbon Fibers opens new plant in Washington,” under "Editor's Picks"). “They can have a linear spring rate or a progressive spring rate — multistage springs — and must perform better with respect to torsion and side stiffness than transversal springs.”

**Higher speed, greater volume**

To date, commercial glass- and carbon-reinforced composite leaf springs have been limited to low-volume production models. “When resins were first being used in the automotive industry, epoxy systems already proven in the aerospace industry were the first to be selected,” explains Scott Simmons, business development specialist for chassis, Henkel Corp. (Madison Heights, Mich.). “While these epoxy systems provide a very high-performing part, the prepreg manufacturing process primarily employed with these resin systems is better suited for the low-volume production associated with aerospace.”

Epoxy prepreg systems weren’t fast reacting because they didn’t need to be for autoclave processing, which, for purposes of quality assurance to high aerospace standards, necessarily involved slow and carefully controlled applications of temperature and pressure. However, much research has gone into expediting the production process through the use of faster melding processes and the development and use of suitably fast-reacting resin systems. These emerging systems show promise for economical mass production of composite leaf springs.

![Figure 3.2 New generation composite leaf springs](http://www.iaeme.com/ijmet/index.asp)
2.5. Literature Review
Leaf springs are mainly used in suspension systems to absorb shock loads in automobiles like light motor vehicles, heavy duty trucks and in rail systems. It carries lateral loads, brake torque, driving torque in addition to shock absorbing [1].

The advantage of leaf spring over helical spring is that the ends of the spring may be guided along a definite path as it deflects to act as a structural member in addition to energy absorbing device [2].

According to the studies made a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring [3].

To meet the need of natural resources conservation, automobile manufacturers are attempting to reduce the weight of vehicles in recent years [4].

Weight reduction can be achieved primarily by the introduction of better material, design optimization and better manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles unsprung weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. The introduction of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness[5].

For weight reduction in automobiles as it leads to the reduction of un-sprung weight of automobile. The elements whose weight is not transmitted to the suspension spring are called the un-sprung elements of the automobile. This includes wheel assembly, axles, and part of the weight of suspension spring and shock absorbers. The leaf spring accounts for 10-20% of the un-sprung weight [6].

The composite materials made it possible to reduce the weight of machine element without any reduction of the load carrying capacity. Because of composite material’s high elastic strain energy storage capacity and high strength-to-weight ratio compared with those of steel [7],[8].

FRP springs also have excellent fatigue resistance and durability. But the weight reduction of the leaf spring is achieved not only by material replacement but also by design optimization. Weight reduction has been the main focus of automobile manufacturers in the present scenario. The replacement of steel with optimally designed composite leaf spring can provide 85% weight reduction. Moreover the composite leaf spring has lower stresses compared to steel spring. All these will result in fuel saving which will make countries energy independent because fuel saved is fuel produced.

2.6. Problem Definition
The suspension leaf spring is one of the potential items for weight reduction in automobile as it accounts for ten to twenty percent of the un-sprung weight. The introduction of composites helps in designing a better suspension system with better ride quality if it can be achieved without much increase in cost and decrease in quality and reliability. The relationship of the specific strain energy can be expressed as it is well known that springs, are designed to absorb and store energy and then release it slowly. Ability to store and absorb more amount of strain energy ensures the comfortable suspension system.

It can be easily observed that material having lower modulus and density will have a greater specific strain energy capacity. The introduction of composite materials made it possible to reduce the weight of the leaf spring without reduction of load.
carrying capacity and stiffness due to more elastic strain energy storage capacity and High strength to weight ratio.

3. DESIGN OF LEAF SPRING

3.1. Model-Mahindra “Model-Ommander 650 Di”
Number of leaf springs = 10
Overall length of the spring = \(2L_1 = 115\text{cm} = 1150\text{mm}\)

Width of leaves = 50 mm
Assuming factor of safety = 1.33

Number of full length leaves = \(2 = N_f\)
Number of graduated leaves = \(8 = N_g\)

Number of springs = \(10 = (N_g + N_f)\)
Center load = \(2W = 1910\text{kg}\)

\(2W = 1910 \times 10 \times 1.33\) is nearly 25403 N

\(2W = 25403/4 = 6350.7\text{N}\)

\(W = 3200 \text{ N nearly}\)

Material used for leaf spring: structural steel

\(bending stress = \frac{6wl}{nb \times t^2}\)

\(\text{bending stress} = \frac{6 \times 1600 \times 560}{10 \times 50 \times 6^2}\)

= 299 N/mm²

\(\delta_r = \frac{12wl^3}{ebt^3 (2n_c + 3n_f)}\)

= 67.5 mm

\(\text{length of leaf} = \frac{\text{effective length}}{\text{no of leafs} - 1} + \text{in effective length}\)

Effective length = 1120 mm, ineffective length = 90 mm, no of full length leafs = 2, graduated length leafs = 8, Total leafs = 10.

Length of smallest leaf (leaf 1) = \(\frac{1120}{10-1} + 90 = 214 \text{ mm}\)

\(\text{length of 2nd leaf} = \frac{1120}{10-1} \times 2 + 90 = 338 \text{ mm}\)

\(\text{length of 3rd leaf} = \frac{1120}{10-1} \times 3 + 90 = 463 \text{ mm}\)

\(\text{length of 4th leaf} = \frac{1120}{10-1} \times 4 + 90 = 588 \text{ mm}\)
Design and Analysis of Leaf Spring by Using Composite Material For Light Vehicles

3.2 Weight Calculations

For steel,

Weight of smallest leaf (leaf1) = \( \text{density} \times \text{volume} \times \text{acceleration due to gravity} \)
\[
= 214 \times 6 \times 50 \times 0.00000786 \times 10
= 5.046 \text{ N}
\]
Weight of leaf2 = \( 338 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 7.97N
Weight of leaf3 = \( 463 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 10.91N
Weight of leaf4 = \( 588 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 13.86N
Weight of leaf5 = \( 712 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 16.78N
Weight of leaf6 = \( 837 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 19.73N
Weight of leaf7 = \( 961 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 22.66N
Weight of leaf8 = \( 1085 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 25.58N
Weight of leaf9 = \( 1120 \times 6 \times 50 \times 0.00000786 \times 10 \)
= 26.40N
Weight of leaf10 = 26.40N
Total weight of steel leaf spring = 175.336N

For Eglass/epoxy,

Weight of mono leaf spring = \( 1120 \times 24 \times 50 \times 0.000002 \times 10 \)
= 26.88N

Weight saved = 175.336 – 26.88 = 148.456N
% weight saved = \( \frac{148.456}{175.336} \times 100 \)
= 84.66%
Table 1 Mechanical Properties of Steel

<table>
<thead>
<tr>
<th>Mechanical</th>
<th>Symbols</th>
<th>Units</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>E</td>
<td>Gpa</td>
<td>207</td>
</tr>
<tr>
<td>Shear modulus</td>
<td>G</td>
<td>Gpa</td>
<td>80</td>
</tr>
<tr>
<td>Poisson’s ratio</td>
<td>µ</td>
<td>-</td>
<td>0.3</td>
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<tr>
<td>Density</td>
<td>p</td>
<td>Kj/m³</td>
<td>7600</td>
</tr>
<tr>
<td>Yield strength</td>
<td>Sy</td>
<td>Mpa</td>
<td>370</td>
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</table>

Table 2 Properties of composite materials

<table>
<thead>
<tr>
<th>S. No</th>
<th>Properties</th>
<th>Eglass/Epoxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>EX(MPa)</td>
<td>43000</td>
</tr>
<tr>
<td>2</td>
<td>EY(MPa)</td>
<td>6500</td>
</tr>
<tr>
<td>3</td>
<td>EZ(MPa)</td>
<td>6500</td>
</tr>
<tr>
<td>4</td>
<td>PRXY</td>
<td>0.27</td>
</tr>
<tr>
<td>5</td>
<td>PRYZ</td>
<td>0.06</td>
</tr>
<tr>
<td>6</td>
<td>PRZX</td>
<td>0.06</td>
</tr>
<tr>
<td>7</td>
<td>GX(MPa)</td>
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<tr>
<td>8</td>
<td>GY(MPa)</td>
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<td>GZ(MPa)</td>
<td>2500</td>
</tr>
<tr>
<td>10</td>
<td>p</td>
<td>0.000002</td>
</tr>
</tbody>
</table>

3.3 Pro/ENGINEER Wildfire Benefits

- Unsurpassed geometry creation capabilities allow superior product differentiation and manufacturability
- Fully integrated applications allow you to develop everything from concept to manufacturing within one application
- Automatic propagation of design changes to all downstream deliverables allows you to design with confidence
- Complete virtual simulation capabilities enable you to improve product performance and exceed product quality goals
- Automated generation of associative tooling design, assembly instructions, and machine code allow for maximum production efficiency

Pro ENGINEER can be packaged in different versions to suit your needs, from Pro/ENGINEER Foundation XE, to Advanced XE Package and Enterprise XE Package, Pro/ENGINEER Foundation XE Package brings together a broad base of functionality. From robust part modelling to advanced surfacing, powerful assembly modelling and simulation, your needs will be met with this scaleable solution. Flex3C and Flex Advantage Build on this base offering extended functionality of your choosing.
Figure 3.1 Master leaf modelled in pro/e 5.0
Dimension have considered in master leaf

Figure 3.2 Assemble model developed in PRO/E 5.0

4. ANALYSIS IN ANSYS

4.1. Introduction
ANSYS is general-purpose finite element analysis (FEA) software package. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of user-designated size) called elements. The software implements equations that govern the behaviour of these elements and solves them all; creating a comprehensive explanation of how the system acts as a whole. These results then can be presented in tabulated, or graphical forms. This type of analysis is typically used for the design and optimization of a system far too complex to analyze by hand. Systems that may fit into this category are too complex due to their geometry, scale, or governing equations.

ANSYS is the standard FEA teaching tool within the Mechanical Engineering Department at many colleges. ANSYS is also used in Civil and Electrical Engineering, as well as the Physics and Chemistry departments.
ANSYS provides a cost-effective way to explore the performance of products or processes in a virtual environment. This type of product development is termed virtual prototyping.

With virtual prototyping techniques, users can iterate various scenarios to optimize the product long before the manufacturing is started. This enables a reduction in the level of risk, and in the cost of ineffective designs. The multifaceted nature of ANSYS also provides a means to ensure that users are able to see the effect of a design on the whole behavior of the product, be it electromagnetic, thermal, mechanical etc.

4.2. Generic Steps to Solving Any Problem in Ansys

Like solving any problem analytically, you need to define (1) your solution domain, (2) the physical model, (3) boundary conditions and (4) the physical properties. You then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise too complex situation. Below describes the processes in terminology slightly more attune to the software.

4.2.1. Build Geometry

Construct a two or three dimensional representation of the object to be modeled and tested using the work plane coordinate system within ANSYS.

4.2.2. Define Material Properties

Now that the part exists, define a library of the necessary materials that compose the object (or project) being modeled. This includes thermal and mechanical properties.

4.2.3. Generate Mesh

At this point ANSYS understands the makeup of the part. Now define how the modeled system should be broken down into finite pieces.

4.2.4. Apply Loads

Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions.

4.2.5. Obtain Solution

This is actually a step, because ANSYS needs to understand within what state (steady state, transient… etc.) the problem must be solved.

4.2.6. Present the Results

After the solution has been obtained, there are many ways to present ANSYS’ results, choose from many options such as tables, graphs, and contour plots.

4.3. Specific Capabilities of Ansys

Structural

Structural analysis is probably the most common application of the finite element method as it implies bridges and buildings, naval, aeronautical, and mechanical
Design and Analysis of Leaf Spring by Using Composite Material For Light Vehicles

structures such as ship hulls, aircraft bodies, and machine housings, as well as mechanical components such as pistons, machine parts, and tools.

4.3.1. Static Analysis
Used to determine displacements, stresses, etc. under static loading conditions. ANSYS can compute both linear and nonlinear static analyses. Nonlinearities can include plasticity, stress stiffening, large deflection, large strain, hyper elasticity, contact surfaces, and creep.

4.3.2. Modal Analysis
A modal analysis is typically used to determine the vibration characteristics (natural frequencies and mode shapes) of a structure or a machine component while it is being designed. It can also serve as a starting point for another, more detailed, dynamic analysis, such as a harmonic response or full transient dynamic analysis.

Modal analyses, while being one of the most basic dynamic analysis types available in ANSYS, can also be more computationally time consuming than a typical static analysis. A reduced solver, utilizing automatically or manually selected master degrees of freedom is used to drastically reduce the problem size and solution time.

4.4. Analysis Results

FOR STEEL

![Deformations In Steel](image1)

**Figure 1** Deformations In Steel

Values of deformation:
- Maximum: 73.909mm

![Stresses in Steel](image2)

**Figure 2** Stresses in Steel
Values of von mises stresses:
Maximum: 352.917MPa

For E-glass/epoxy,

Values of deformation:
Maximum: 52.346mm

Values of von-mises stresses:
Maximum: 178.356MPa

4.4.1. Fatigue Analysis of Steel At Fixed Support

<table>
<thead>
<tr>
<th>Events</th>
<th>Loads (N)</th>
<th>Applied cycles</th>
<th>Stress intensity MPa</th>
<th>no. cycles</th>
<th>Partial usage</th>
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<tbody>
<tr>
<td>1</td>
<td>1600</td>
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<td>5000</td>
<td>50,000</td>
<td>954.48</td>
<td>10</td>
<td>5000</td>
</tr>
</tbody>
</table>
4.4.2. Fatigue Analysis of Eglass/Epoxy At Fixed Support

Table (4.4.2)

<table>
<thead>
<tr>
<th>Events</th>
<th>Loads</th>
<th>Applied cycles</th>
<th>Stress intensity MPa</th>
<th>no. cycles</th>
<th>Partial usage</th>
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</tbody>
</table>

Graph:1 Usage factor comparison for steel and Eglass/epoxy

Graph:2 Stress intensities vs load for steel and Eglass/epoxy
Graph: 3 Resultant deformation in steel and Eglass/epoxy

Graph 4 The stress comparison between steel and Eglass

5. CONCLUSION

1. As leaf spring contributes considerable amount of weight to the vehicle and needs to be strong enough, a single composite leaf spring is designed and it is shown that the resulting design and simulation stresses are much below the strength properties of the material satisfying the maximum stress failure criterion.

2. From the static analysis results, we see that the von- mises stress in the steel is 352.917 MPa. And the von- mises stress in Eglass/Epoxy is 178.356 MPa.

Epoxy is 178.356 MPa.

1. Composite mono leaf spring reduces the weight by nearly 84% for E-Glass/Epoxy.

2. From the fatigue analysis results, the usage factor of Eglass/Epoxy is very much less compared to steel. Hence it is advantageous to replace steel leaf spring with Eglass/Epoxy.
REFERENCES

[14] Mechanical Properties of Composite Material Reinforced by Jute and E-Glass Fibers B Durga Prasad1 , G. Kiran Reddy1 , A. Anusha Yadav1