Behavior and Analysis of Orthotropic Laminated Composite

DISSERTATION- II

Submitted in Partial Fulfilment of the

Requirement for Award of the Degree

Of

MASTER OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

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CERTIFICATE

I hereby certify that the work which is being presented in the Dissertation-II entitled **"Behavior And Analysis Of Orthotropic Laminated Composite"** partial fulfilment of the requirement for the award of degree of **Master of Technology** and submitted in Department of Mechanical Engineering, Lovely Professional University, Punjab is an authentic record of my own work carried out during period of Dissertation under the supervision of **Mr. Prashant Bagde**, **Assistant Professor** , Department of Mechanical Engineering, Lovely Professional University, Punjab.

The matter presented in this Dissertation-II has not been submitted by me anywhere for the award of any other degree or to any other institute.

Date: **Mr. Akash Deep**

This is to certify that the above statement made by the candidate is correct to best of my knowledge.

Date: **Mr. Prashant Bagde**

Supervisor

M-Tech Dissertation-II examination of has been held on Behavior and Analysis of Orthotropic Laminated Composite

Signature of Examiner

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ABSTRACT

It has been currently seen that automobile industry has shown a keen interest in replacing steel leaf spring with composite leaf spring because of its higher strength to weight ratio. The basic need is to change the multi leaf springs attached in the vehicle with the mono leaf springs. The purpose of leaf springs attached in a vehicle is for better riding comfort for the passenger as it works as a suspension system and determines the damage produced over the vehicle. The function of suspension system is to support vertical load applied over it and to isolate the induced vibrations produced in it. The need for this study is to study the behavioral analysis of multi leaf steel spring with a mono composite leaf spring while having the increase amount of load bearing capacity and decreasing the amount of deflection produced in it.

Composite material usually have various helpful properties like high strength to weight ratio, easy method for fabrication, acceptable amount of electrical and thermal properties as compared to the metals and can store more amount of elastic strain energy. We know that laminated composite material have many layers of composite mixture of matrix and fibers. The orientation of those laminates can be in a similar manner or in a dissimilar manner it generally depend upon the need for the fabrication. There are various aspects of designing a laminated composites. Over this both laminate theory and numerical methods have been used for doing an analysis. In a similar manner a analysis is done over a mono leaf spring which is made up of carbon epoxy material. While inputting the number of layers and the orthotropic properties of each layer to calculate the extension bending, bending stiffness matrix and coupling stiffness matrix and further we can determine the elastic constants, poison’s ratio and the density.

The analysis is being done over the ANSYS software

Chapter 1

1 Composites

1.1 Introduction to Composite

The term composite means involving two or more than two distinct parts hence a material having two or more than two distinct materials can be called a composite material. A composite material can be found out by checking its material properties. Usually composite materials are being used in Aircraft, Marine, Transport areas along with areas like construction, electrical and corrosion and various other places

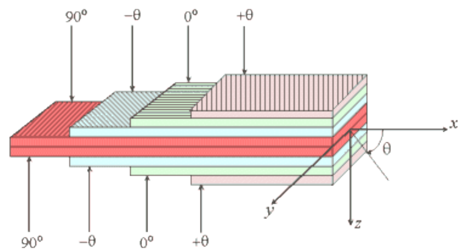

Figure 1. 1 *Laminate Orientation*

Now a days composite materials are being used to get past a certain balance in the material properties for various range of the applications. It may be tuff to stick for one simple and easy definition depending upon the use of composite material and also upon the variety of the material present for replacing the conventional material.

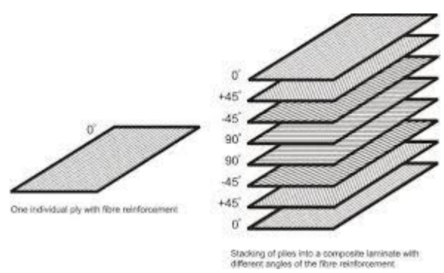

Figure 1. 2 Orientation of Laminates in different directions

In any case, as a commonplace valuable definition, composite materials may be kept to underscore those materials that contain a constant grid constituent that ties together and offers structure to a display of a stronger, stiffer fortress constituent. The resulting composite material has a balanced of helper properties that is superior to either constituent material alone.
The upgraded assistant properties generally come about because of a store offering segment. Composites streamlined for other helpful properties could be conveyed from absolutely particular constituent blends than fit this assistant definition, it has been watched that composites made for fundamental applications similarly give engaging execution in these other viable locales too.

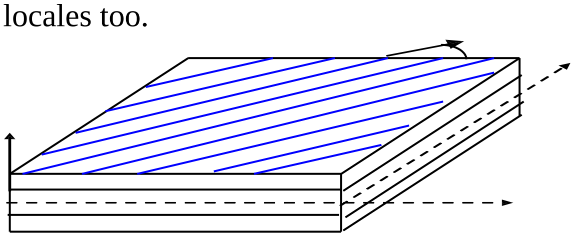

Figure 1. 3 Layup of Laminates

In this manner, composites commonly have a fiber or molecule stage that is stiffer and stronger than the ceaseless lattice stage. Numerous sorts of fortifications likewise regularly have great warm and electrical conductivity, a coefficient of warm extension (CTE) that is not exactly the grid, and/ or great wear resistance.

There are, be that as it may, exemptions that may in any case be viewed as composites, for example, elastic altered polymers, where the intermittent stage is more agreeable and more malleable than the polymer, bringing about enhanced strength. Also, steel wires have been utilized to strengthen dark cast press in truck and trailer brake drums.

1.2 Classification of Composites

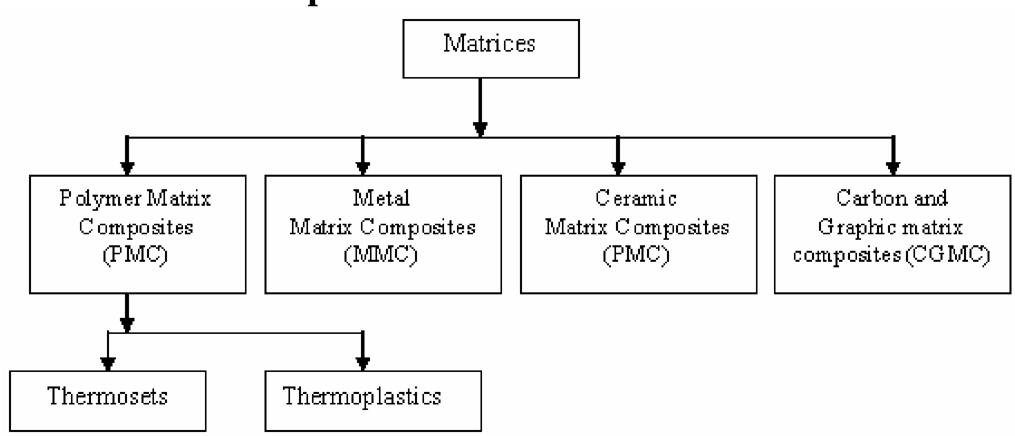

Figure 1. 4 Classification of Composites

Composites are commonly classified at two distinct levels.
The first level of classification is usually made with respect to the matrix constituent. The major composite classes include

1.) Polymer Matrix Composite
2.) Metal Matrix Composites
3.) Ceramics Matrix Composite

The articulation "common matrix composite" is generally anticipated that would fuse two classes of composites: polymer-grid composites (PMCs) and carbon-network composites (routinely implied as carbon-carbon composites). Carbon-grid composites are customarily formed from PMCs by including the extra ventures of carbonizing and densifying the first polymer system. In each of these structures, the system is routinely a steady stage all through the section.

The second level of classification refers to the reinforcement form

1.) Particulate
2.) Whiskers
3.) Continuous fiber laminated
4.) Woven Composites

With a particular deciding objective to give an important addition in properties, there all around must be a liberal volume division (10% or more) of the fortress. A fortress is thought to be a "particle" if every single bit of its estimations are by and large equal.

Accordingly, particulate-reinforced composites consolidate those invigorated by circles, posts, chips, and various diverse conditions of by and large identical tomahawks.

Constant fiber-invigorated composites contain fortresses having lengths substantially more noticeable than their cross-sectional estimations. Such a composite is thought to be a broken fiber or short fiber composite if its properties change with fiber length. On the other hand, when the length of the fiber is such that any further augmentation long does not.

A valid example, further grow the adaptable modulus or nature of the composite, the composite is thought to be nonstop fiber braced. Most incessant fiber (or diligent fiber) composites, undoubtedly, contain strands that are proportional long to the general estimations of the composite part.

Each layer or "utilize" of a steady fiber composite ordinarily has a specific fiber presentation heading. These layers can be stacked such that each layer has a foreordained fiber presentation, therefore giving the entire overlaid stack ("overlay") significantly tailor-capable general properties. Obfuscating the importance of a composite as having both steady and unpredictable stages is the route that in a secured composite, neither of these stages may be seen as truly incessant in three estimations.

1.3 Carbon Matrix Composites

Polymers make perfect materials as they can be handled effectively, have lightweight, and alluring mechanical properties. It takes after, subsequently, that high temperature saps are broadly utilized as a part of aeronautical applications.

Two primary sorts of polymers are thermosets and thermoplastics.

Thermosets have qualities, for instance, an all that much strengthened three-dimensional sub-nuclear structure in the wake of curing. They rot rather than dissolving on hardening. Simply changing the central association of the pitch is sufficient to change the conditions suitably for curing and center its diverse traits. They can be held in a to some degree cured condition too over postponed times of time, rendering Thermosets particularly versatile. Thusly, they are most suited as grid bases for front line conditions fiber braced composites. Thermosets find unfathomable applications in the divided fiber composites shape particularly when a premixed or trim compound with fibers of specific quality and perspective extent happens to be starting material as in epoxy, polymer and phenolic polyamide pitches.

Thermoplastics have one- or two-dimensional sub-nuclear structure and they tend to at a raised temperature and show exaggerated dissolving point. Another inclination is that the approach of softening at raised temperatures can changed to recover its properties in the midst of cooling, empowering uses of conventional pack techniques to shape the blends.
Resins fortified with thermoplastics now included a developing gathering of composites. The topic of most trials around there to enhance the base properties of the saps and concentrate the best useful preferences from them in new parkways, including endeavors to supplant metals in pass on throwing courses of action.

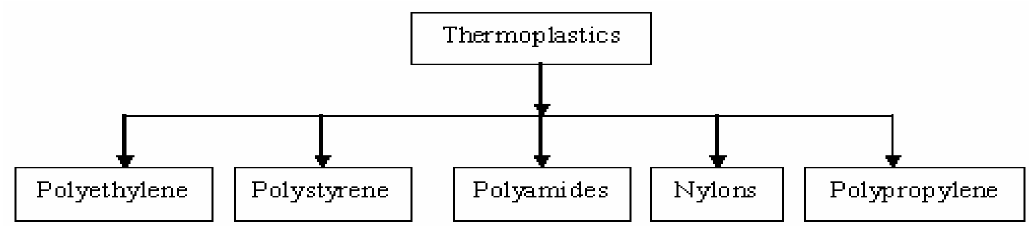

Figure 1. 5 Shows kinds of thermoplastics

A little quantum of shrinkage and the inclination of the shape to hold its unique structure are additionally to be represented. Anyhow, fortifications can change this condition as well. The benefit of thermoplastics frameworks over thermosets are that there are no chemical responses included, which frequently bring about the arrival of gasses or warmth. Assembling is restricted when needed for warming, forming and cooling the structures.

Thermoplastics tars are sold as moulding compounds. Fiber fortification is well-suited for these resins. Since the filaments are haphazardly scattered, the fortification will be just about isotropic. Then again, when subjected to trim methodologies, they can be adjusted directionally. There are a couple of alternatives to build heat resistance in thermoplastics. Expansion of fillers raises the warmth resistance. At the same time, every single thermoplastic composite tend lose their quality at raised temperatures. Notwithstanding, their saving graces like unbending nature, strength and capacity to deny deadhead, place thermoplastics in the critical composite materials section. They are utilized as a part of auto control boards, electronic items encasement and so on. Immense sheets of strengthened thermoplastics are presently accessible and they just oblige testing and warming to be shaped into the obliged shapes. This has encouraged simple creation of massive segments, getting rid of the more unwieldy trim mixes. Thermosets are the most prominent of the fiber composite networks without which, innovative work in basic designing field could get truncated. Aviation segments, auto parts, safeguard frameworks and so forth, utilize a lot of this kind of fiber composites. Epoxy network materials are utilized as a part of printed circuit sheets and comparable territories.

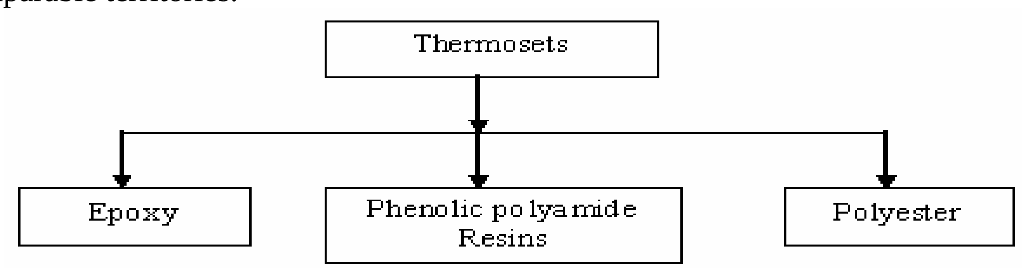

Figure 1. 6 Shows some kinds of thermosets.

Polyesters and Epoxies are the two important classes of thermoset resins.

Epoxy resins are broadly utilized as a part of fiber wound composites and are suitable for moulding purpose. They are sensibly steady to concoction assaults and are magnificent disciples having moderate shrinkage amid curing and no discharge of unpredictable gasses. These points of interest, notwithstanding, make the utilization of epoxies rather lavish. Additionally, they can't be normal past a temperature of 140ºC. Their utilization in high innovation ranges where administration temperatures are higher, thus, is precluded.

Polyester resin are effortlessly available, shabby and discover use in an extensive variety of fields. Fluid polyesters are put away at room temperature for quite a long time, infrequently for a considerable length of time and the negligible expansion of an impetus can cure the lattice material inside a brief while. They are utilized as a part of auto and basic applications.

Chapter 2

2 Scope of the Study

In now a day the fuel proficiency and discharge gas regulation of autos are two vital issues. To satisfy this issue the car commercial ventures are attempting to make new vehicle which can give high proficiency ease. The most ideal approach to build the fuel proficiency is to decrease the heaviness of the auto. The weight diminishment can be attained to essentially by the presentation of better material, plan enhancement and better assembling courses of action. The accomplishment of weight diminishment with sufficient change of mechanical properties has made composite a decent swap material for routine steel. A leaf spring is a straightforward manifestation of spring, ordinarily utilized for the suspension in wheeled vehicles. The suspension of leaf spring is the region which needs to center to enhance the suspensions of the vehicle for solace ride. The suspension leaf spring is one of the potential things for weight decrease in vehicles as it records for 10 to 20% of un-sprung weight. It is remarkable that springs are intended to retain stuns. So the strain vitality of the material turns into a central point in outlining the springs. The presentation of composite material will make it conceivable to lessen the heaviness of the leaf spring without decrease in burden conveying limit and firmness. Since the composite material have high quality to weight degree and have more versatile strain vitality stockpiling limit as contrasted and steel.
The relationship of specific strain energy can be expressed as:-

$$\mathbf{U= S^2 /d*E}$$

Where S is the strength, d is the density if the material and E is the Young's Modulus of the spring material. From the above shown relation we can directly see that strain energy is directly proportional to the strength and is inversely proportional to the Young's modulus hence these are the important parameter's which are to be kept in mind while selecting the material.

2.1 Types of spring

1.) Helical springs
2.) Conical and volute springs
3.) Torsion springs
4.) Disc or Belleville springs
5.) Special purpose springs
6.) Laminated or leaf springs

Spring is characterized as a versatile body, whose capacity is to twist when stacked and to recuperate its unique shape when the heap is uprooted. Springs are flexible bodies that can be curved, pulled or extended by some power. They can come back to their unique shape when the power is discharged. Leaf spring (otherwise called level springs) is made out of level plate. The point of interest in leaf spring over helical spring is that the finishes of the spring may be guided along a clear way as it diverts to go about as an auxiliary part moreover the vitality engrossing gadget. Therefore the leaf springs may convey horizontal burdens, brake torque, driving torque and so on notwithstanding stuns.

2.2 Construction of Leaf Spring

A leaf spring regularly utilized as a part of vehicles is of semi-circular structure. It is developed of various plates (known as clears out). The leaves are typically given a beginning shape or cambered with the goal that they will have a tendency to straighten under the heap. The leaves are held together by method for a band contracted around them at the middle or by a jolt going through the core. Since the band applies solidifying and fortifying impact, along these lines the viable length of the spring for bowing will be general length of the spring less width of band. If there should be an occurrence of a middle jolt, two-third separation between focuses' of U-jolt ought to be subtracted from the general length of the spring keeping in mind the end goal to discover successful length. The spring is braced to the pivot lodging by method for U-jolts

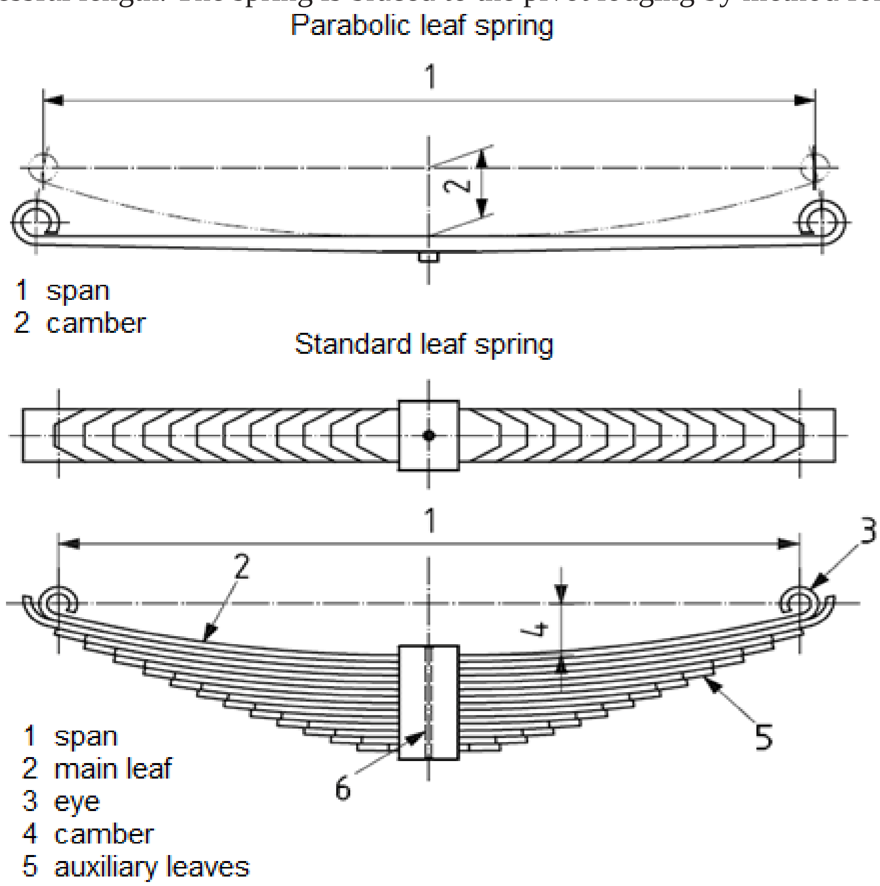

Figure 2. 1 Figure of Leaf Spring

The longest leaf known as principle leaf or expert leaf has its closures shaped fit as a fiddle of an eye through which the jolts are gone to secure the spring to its backings. Normally the eyes, through which the spring is appended to the clothes rod or shackle, are furnished with bushings of some antifriction material, for example, bronze or elastic. Alternate leaves of the spring are known as graduated takes off. With a specific end goal to forestall diving in the neighbouring leaves, the finishes of the 8 graduated leaves are trimmed in different structures. Since the expert leaf needs to with stand vertical curving loads and also stacks because of sideways of the vehicle and contorting, hence because of the vicinity of hassles brought about by these heaps

Rebound clasps are situated at transitional positions in the length of the spring, so that the graduated leaves likewise impart the anxieties prompted in the full length leaves when the spring bounce back.

2.3 Standard Sizes of Suspension Leaf Spring

1.) Standard ostensible widths are 32,40,45,55,60,65,70,75,80,90,100 and 125 mm.
2.) Standard ostensible thickness are 3.2,4.5,5,6,6.5,7,7.5,8,9,10,11,12,14 and 16 mm.
3.) At the eye, the accompanying bore width are prescribed 19,20,22,23,25,27,28, 30,32,35,38 mm

2.4 Application of Leaf Spring

1.) To pad, ingest or control vitality because of either stun or vibration as in auto springs, track cushions, air-specialty landing apparatuses, safeguards and vibration dampers.
2.) To apply compels, as in brakes, grasps and spring stacked valves.
3.) To control movement by keeping up contact between two components as in cams and adherents.
4.) To measure strengths, as in spring offsets and motor markers.
5.) To store vitality, as in watches,

2.5 Characteristics of Leaf Spring

1.) The leaf spring goes about as a linkage for holding the hub in position and along these lines separate linkage are redundant. It makes the development of the suspension basic and solid.
2.) The situating of the hub is done by the leaf springs so it makes it disadvantageous to utilize delicate springs i.e. a spring with low spring consistent.
3.) This sort of suspension does not give great riding solace. The between leaf grinding between the leaf springs influences the riding solace.
4.) Acceleration and braking torque reason wind-up and vibration. Likewise end up reasons backside squat and nose diving

2.6 Material Used For Leaf Spring

The material used for leaf springs is typically a plain carbon steel having 0.90 to 1.0% carbon. The leaves are warmth treated after the forming methodology. The glow treatment of spring steel creates more huge quality and thusly more essential weight limit, more conspicuous extent of redirection and better shortcoming properties. Materials constitute just about 60%-70% of the vehicle cost and add to the quality and the execution of the vehicle. For sure, even a little entirety in weight reducing of the vehicle, may have a more far reaching financial impact.

Composite materials are exhibited as suitable substitutes for steel in regards to weight diminishment of the vehicle. Hence, the composite materials have been picked for leaf spring diagram. The material of the spring ought to have high weariness quality, high malleability, high flexibility and it ought to be crawl safe.It generally relies on the administration for which they are utilized i.e. serious administration, normal administration or light administration. Extreme administration implies fast persistent stacking where the proportion of least to greatest load (or anxiety) is one-half or less, as in auto valve springs. Normal administration incorporates the same anxiety go as in serious administration however with just discontinuous operation, as in motor representative springs and vehicles suspension springs. Light administration incorporates springs subjected to loads that are static or occasionally changed, as in security valve springs.

2.7 Why a Composite?

Throughout the most recent thirty years composite materials, plastics and ceramics have been the prevailing rising materials. The volume and number of utilizations of composite materials have developed relentlessly, infiltrating and vanquishing new markets constantly. Advanced composite materials constitute a critical extent of the designed materials business extending from regular items to complex specialty applications. While composites have officially demonstrated their value as weight-sparing materials, the current test is to make them savvy. The endeavors to create monetarily appealing composite segments have brought about a few inventive assembling strategies right now being utilized as a part of the composites business.

It is self-evident, particularly for composites, that the change in assembling innovation alone is insufficient to beat the expense obstacle. It is vital that there be an incorporated exertion in outline, material, methodology, tooling quality certification, assembling, and even program administration for composites to turn into aggressive with metals.

Further, the need of composite for lighter development materials and more seismic safe structures has set high accentuation on the utilization of new and propelled materials that reductions dead weight as well as retains the stun & vibration. Composites are currently widely being utilized for recovery/ reinforcing of prior structures that must be retrofitted to make them seismic safe, or to repair harm created by seismic movement. Dissimilar to traditional materials (e.g. steel), the properties of the composite material can be planned considering the auxiliary angles. The configuration of an auxiliary segment utilizing composites includes both material and basic outline. Composite properties (e.g. solidness,) can be fluctuated consistently over a wide scope of qualities under the control of the originator. Cautious choice of support sort empowers completed item qualities to be customized to any particular designing necessity. Whilst the utilization of composites will be an unmistakable decision in numerous examples, material choice in others will rely on upon components, for example, working lifetime necessities, number of things to be delivered (run length), many-sided quality of item shape, conceivable reserve funds in get together expenses and on the experience & aptitudes the fashioner in tapping the ideal capability of composites. In a few examples, best results may be accomplished through the utilization of composites in conjunction with customary materials.

Chapter 3

3 Objectives

The utilization of composite material will help to comprehend the fundamental anxiety examination strategies which are utilized to focus the material properties, for example, the modulus of flexibility and the Poisson's proportion. This could likewise be accustomed to deciding other material properties, for example, relative point of confinement, yield quality, extreme quality, or crack quality of a material.

It serves to comprehend that material properties are not steady under diverse kind of burden setup. In the meantime, we may discover that these material properties could be dead set from distinctive sort of testing.

The greatest point of interest of present day composite materials is that they are light and additionally solid. By picking a fitting mix of lattice and support material, another material can be made that precisely meets the necessities of a specific application. Composites additionally give Design adaptability in light of the fact that a considerable lot of them can be shaped into complex shapes. The drawback is regularly the expense. Despite the fact that the subsequent item is more effective, the crude materials are frequently lavish.

In the current study we are more interested to see that how the orthotropic material behaves while applying different loading conditions over it while changing the various fiber orientations in the composite laminates. The behavior is much observed at the center and at the ends of the leaf spring which is made of composite material which is carbon epoxy.

Chapter 4

4 Literature Review

[M. M. Patunkar *et al*, 2011][1] Leaf springs are one of the most seasoned suspension segments they are still habitually utilized, particularly in business vehicles. The past writing study demonstrates that leaf springs are composed as summed up power components where the position, speed and introduction of the hub mounting gives the response drives in the undercarriage connection positions. The auto business has indicated expanded enthusiasm for the supplanting of steel spring with composite leaf spring because of high quality to weight proportion. Consequently, investigation of the composite material gets to be similarly critical to study the conduct of Composite Leaf Spring. The goal of this paper is to present demonstrating and investigation of composite mono leaf spring. Numerous modern visits, past recorded information demonstrates that steel leaf springs are produced by EN45, EN45A, 60Si7, EN47, 50Cr4V2, 55SiCr7 and 50CrMoCV4 and so forth. These materials are broadly utilized for generation of the illustrative leaf springs and ordinary multi leaf springs. A composite mono leaf spring with a necessary eye was made and tried for the static burden conditions. Exhaustion life forecast was additionally done by creators in order to guarantee a solid number of life cycles of a leaf spring. Further, a leaf spring had been displayed in routine way and recreated for the kinematic and element comparatives. Cyclic deadhead and cyclic twisting was additionally concentrated on. Customary leaf spring is initially tried under static load. Condition by utilizing Hydraulic Static Load Test. On applying the similar boundary condition over the steel and composite leaf spring huge difference was seen into effect. The amount of deflection produced in the composite leaf spring is very less as when compared to the steel leaf spring when placed in the similar conditions. It was noticed that weight of steel spring was 23 kg as compared to 3.59 kg of the composite leaf spring. From this it is seen that amount of weight reduction was seen of around 84.40%.

[Parkhe Ravindra *et al*, 2014][2]This paper delineates diagram and examination of composite mono leaf spring. Weight diminishment is shortly the essential issue in auto business wanders. A composite mono leaf spring with Carbon/Epoxy composite materials is exhibited and subjected to the same load as that of a steel spring. The framework objectives were bothers and shirking's. The composite mono leaf springs have been shown by considering Varying cross-section, with unidirectional fiber presentation plot for each lamina of a spread. The overview generally spotlights on supplanting of steel leaf spring with the composite leaf spring made of glass fiber invigorated polymer (GFRP) and lion's offer of the appropriated work applies to them. Malaga Anil Kumar et al portrays that three differing composite materials have been used for examination of mono-composite leaf spring. They are E-glass/epoxy, Graphite/epoxy and carbon/epoxy. E-glass/epoxy composite leaf spring can be proposed for supplanting the steel leaf spring both from immovability and tension reason for perspective. A close study has been made amidst steel and composite leaf spring concerning quality and weight. Composite mono leaf spring decreases the weight by 85% for E-Glass/Epoxy, 94.18% for Graphite/Epoxy, and 92.94 % for Carbon/Epoxy over routine leaf spring. For the secluded examination, same utmost conditions are associated and the stack require not be joined. Diverged from mono steel leaf spring the overlaid composite mono leaf spring is found to have 47% lesser bothers, 25%~65%

higher strength, 27%~67% higher repeat and weight diminishment of 73%~80% is accomplished. A relative study has been made between composite leaf spring and steel leaf spring concerning weight and quality. By using a composite leaf spring for the same weight passing on utmost, there is a decreasing in weight of 22.5% than the steel spring. In view of the results, it was derived that carbon/epoxy secured composite mono leaf spring has unrivaled quality and solidness and lesser in weight appeared differently in relation to steel material considered in this examination. From the results, it is viewed that the composite leaf spring is lighter and more proficient than the customary steel spring.

[Patil K.N et al, 2013][3] The Automobile Industry has shown unmistakable interest for supplanting of steel leaf spring with that of Glass fiber composite leaf spring, after the composite material has high caliber to weight degree, awesome disintegration Resistance and tailor-fit properties. The present study searches the new material for leaf spring. In present Study the material picked was glass fiber invigorated plastic (GFRP) and the polyester gum (NETPOL 1011) is used against standard steel. A spring with relentless width and thickness was made by hand lay-up Technique which was to a great degree clear and calm. Weights, preoccupation and strain imperativeness results for both steel and composite leaf spring material were gotten. The material picked for steel leaf spring is 65Si7. Considering the specific strain imperativeness of steel spring and some composite materials, the E-glass/epoxy is picked as the spring material. The 3-D exhibiting of both steel and composite leaf spring is done and examined A relative study has been made amidst composite and steel leaf spring concerning Deflection, strain essentialness and bothers. From the results, it is viewed that the composite leaf spring is lighter and more traditionalist than the customary steel spring with similar layout determinations. It is viewed that the weight diminishing of mono leaf spring is achieved up 84.94% in the occasion of composite than steel. It can be successfully viewed that material having lower modulus and thickness will have a more conspicuous specific strain essentialness limit. The presentation of composite materials was made it possible to diminish the weight of the leaf spring with no abatement on weight passing on farthest point and solidness. Since the composite materials have more adaptable strain imperativeness stockpiling breaking point and high caliber to-weight extent when appeared differently in relation to those of steel. It is viewed that the composite material shows more shirking and strain imperativeness than that of steel material

[Y N V Santhosh Kumar et al, 2012][4] Composite structures for customary metallic structures has various central focuses in light of higher specific strength and nature of composite materials. The auto business has shown extended eagerness for the supplanting of steel spring with fiberglass composite leaf spring due to high caliber to weight degree. This work deals with the substitution of routine steel leaf spring with a Mono Composite leaf spring using E-Glass/Epoxy. The arrangement parameters were picked and separated with the focus of minimizing weight of the composite leaf spring when stood out from the steel leaf spring. The focus of the present work is to arrange the E-Glass/ Epoxy composite leaf spring without change in solidness for auto Suspension system and separate it. This is completed to fulfill the going with to the supplant routine steel leaf springs with E-glass/Epoxy composite leaf spring without change in solidness. To accomplish huge weight diminishment in the suspension system by supplanting steel leaf spring with composite leaf spring. It was viewed that the preoccupation in the composite leaf spring was practically comparable so we can say that composite spring had the same robustness as that of steel spring. It was watched that the composite leaf spring measured just 39.4% of the steel leaf spring for the dissected burdens. Subsequently the weight lessening acquired by utilizing composite leaf spring when contrasted with steel was 60.48 %.By investigating the configuration, it was observed that all the burdens in the leaf spring were well inside as far as possible and with great component of security. It was discovered that the longitudinal introductions of strands in the overlay offered great quality to the leaf spring.

[N Upendra et al, 2013][5] A logical plan and arrangements are created to examine the twisting qualities of overlaid composite plates in view of higher request shear distortion hypothesis. The impact of side to thickness degree, perspective proportion, level of orthotropic, stacking arrangement promotion no of layers on redirection and burdens are examined. The outcomes anticipated by the present hypothesis are in great concurrence with the arrangements of other plate hypotheses accessible. Think about the aftereffect of avoidance for an essentially bolstered orthotropic plate acquired by utilizing the Classical overlaid plate hypothesis, First-arrange shear deformity hypothesis. The outcomes are contrasted regarding side with thickness proportion, perspective degree, diverse stacking grouping and distinctive quantities of layers. Scientific strategy is produced to discover the bowing attributes of overlaid composite plates utilizing higher request hypothesis. A brought together general definition of all higher request speculations has been displayed for composite in light of a polynomial development of removal in the thickness coordinate. The outcomes may be critical to the fashioner in the field of overlaid composite development .It was noticed that distinctive side to thickness degree influenced the diversion. The diversion diminishes as side to thickness degree increments. The lessening of the diversion is uniform with the increment of side to thickness degree. It is watched that, the diversions are bigger for littler modulus degree and angle degrees.

[Zhao Fangxin et al, 2000][6] A definite answer for a consistently stacked rectangular plate with two neighboring edges cinched, one edge just upheld and the other edge free, was given by utilizing the idea of summed up essentially bolstered edges and superposition system. The numerical results were given for the redirections along the free edge and twisting minutes along the braced edges of a square plate. Zhang acquired the accurate answers for the bowing issue of rectangular cantilever plates and rectangular plates which have two neighboring edges clipped and the other two nearby edges free and hold on for concentrated load and uniform burden. This plate may be suitable for some designing applications, for example, tasks of horse shelter, water-storage facility, sensor-based chip and common development. Limit state of basically upheld edges is curving minute M = 0, and diversion W = 0 while that of summed up essentially bolstered edges is M = 0, and 1V ~ 0. In both cases, shearing power exists along the edges. On the off chance that avoidance exists along a basically bolstered edge, this edge is characterized as summed up essentially upheld edge.

[Kumar Krishan and Aggarwal M.L et al 2012][7] This work is done over a multi leaf spring which consist of nine leaves which are being used over a commercial vehicle. A finite modelling and analysis of a multi leaf spring is been carried out. The leaf spring is designed in a way that it has two full length leaves in which eyed ends and there are seven graduated length leaves. The leaf spring used in automotive vehicles generally consist of full length and graduated length leaves. The specimen which is being used under this review work has 9 overall leaves, two eyed pins, center bolt with nuts along with CAE tools for analyzing the performance of the components and the assemblies.

FEA technique is used to obtain approximate solution for the boundary value problems. It has a numerical technique known as finite element method. CAE usually depend upon the actual assumptions which are acting with the input data. This has become an important technology which has the benefits to lower costs and reduce the design cycles. After the various studies we can say that design professional can reduce at least 30% of the time as well as the money just by using CAE tools. This method earlier described is used and performed on the spring model for observing the distribution stresses and damages. The experimental results are being validates with the FEM results. While analysis of conventional spring with composite leaf spring made up of Glass Fiber Reinforced Polymer is being used for analysis. A static analysis for the 2D model is done with the help of ANSYS 7.1 and compared with experimental results. Similar dimension of leaf spring are used to fabricate a composite leaf spring made of E Glass-Epoxy. The main motive is to get the experimental results on a full scale under the static loading conditions in which the leaf spring is held under axial load which is placed at center until there is maximum deflection produced in the leaf spring. The results are compared with FEA results for validation. The boundary condition have different forces, pressure, velocity, supports, and constraints for the complete analysis. The complete analysis id done with the help of ANSYS 11.0 software to conduct the procedural FEA process which has three phases in it. It has been observed that when the leaf spring is fully loaded there is a variation of 0.632% in comparison with the experimental values which is also same in the case of half loading conditions. The bending stresses produced are also approximately similar to the experimental values. The maximum value of equivalent stress is below the yield stress of the material in order to avoid failure.

[GS Shiva Shankar et al 2006][8] As we have seen that automobile industry have shown a keen interest in replacing steel spring with fiber glass composite leaf spring because of its high strength to weight ratio. It is noticed that main purpose is to present a low cost fabrication of mono composite leaf spring with attached end joints. A mono leaf which is having variation in the thickness and its width but having a constant cross sectional area of unidirectional glass fiber reinforced plastic which is having a similar mechanical and geometrical properties of a multi leaf spring. Weight reduction can be achieved primarily by introducing better material, design optimization and much better manufacturing processes. We already know that springs are made to absorb and store the energy and then released it. Just by replacing with composite material weight reduction was achieved while having the same load carrying capacity and stiffness as composite material have more elastic strain energy and high weight to strength ratio as compared to steel. We need to design and analyses and fabricate and test the unidirectional Glass Fiber/Epoxy a mono leaf spring without end joints and spring with attached end joints by using hand lay-up method. This method is preferred over wet filament winding technique because it’s more efficient and economical method. Analysis of leaf spring was done in ANSYS software and with finite element method a stress analysis was done. Main disadvantage of composite leaf spring is the chipping resistance. The matrix component of the composite material chips off when they are placed in a bad environmental condition .It was seen that of about 85%weight was being reduced by using composite leaf spring and the stresses are much lower than the steel spring.

[B.Vijaya Lakshmi et al 2012][9] During the recent events the main objective for the automobile industry is to compare the load carrying capacity, stiffness and weight reduction of the conventional steel spring with the composite manufactured leaf spring. The main purpose which were assumed as constraints during the calculation of the inputs were stresses and deflection which are ultimately produced in the leaf spring. The dimension of leaf spring which were used were conventionally used all over while the composite leaf springs were made from E, S, C Glass Epoxy laminates. The model was made in Pro E and for analyzing the design COSMOS software was being used. Over the leaf spring both static and dynamic analysis was done. Usually over a certain period of time semi elliptic leaf springs are being used for the suspension system for both commercial and heavy loaded vehicles. They are used as rear system suspension in cars. In cars they are placed at the axle of the vehicle and hence the weight of the vehicle rests upon the leaf spring. After the static analysis over the leaf spring of 8 leaves it was concluded that composite E Glass Epoxy is better than mild steel spring. The stresses were a little bit on the higher side than the mild steel but E Glass has a good yield strength value and they can easily be made and are less in weight as compared to other steel spring. We also have analyzed a leaf spring having 12 leaves for that S Glass shows a better result than the C Glass Epoxy material. On using S Glass has resulted in increased the number of leaves in order to reduce the stresses for structural stability. After the results were obtained it was seen that weight has been gradually decreased with respect to the other conventional spring. Hence finally it was concluded that S Glass Epoxy is the best material to manufacture because of its better stability and less production cost and with having a higher efficiency.

[Amol Bhanage et al 2013][10] A review is given regarding the suitability of the composite leaf springs along with their advantages we have seen that much work is done to reduce the cost of the composite leaf springs. Weight reduction from the leaf springs is been done with the help of proper improvement in the mechanical properties of the material which has resulted into replacement of the conventional spring. According to the factor of safety material and the production process is being selected. The production process depends upon the required amount of the need for the material in the industry. It has been seen after the detailed study that the composite leaf springs are higher and more economical than the conventional leaf springs which are generally being used. We know that single leaf springs are the simplest and easiest for of the springs which are mostly used in suspension for the wheeled automobiles. The basic use of suspension system is that they are helpful in power transfer and motion of the vehicle and the driving. With the help of ANSYS software the analytical result is been compared. The main use for this review is to compare the load carrying capacity, stiffness produced, and the overall weight of composite leaf spring in comparison with steel leaf spring. Modern composite fiber such as Glass, Carbon and Kevlar-reinforced resins are expected to be used widely in the suspension application in order to obtain different designs of springs. Material used for the production of leaf spring involves approximate 60-70% of the cost of vehicle and contribute with quality and performance of the vehicle. We have seen that with a small amount of weight reduction in the vehicle it may have a wider economic impact over the automobile. Composite material have shown appropriate substitute for changing steel spring with the composite leaf spring in connection with weight reduction of the vehicle. So the composite material have been finally decided for the production material of the springs. In this review work a comparison of convention spring EN 47 and the composite material leaf spring is being tested under static loading condition hence the model is being designed in Pro-E 4.0 and simulated in ANSYS 14.0 and the results obtained will be concluded with the development of a composite mono leaf spring having similar cross sectional area. Also it seen that stress produced at any level in the spring is considered constant due to parabolic type of thickness of the spring.

[M.Venkatesan et al 2012][11] In this paper an experimental analysis is done over a composite leaf spring made of glass fiber reinforced polymer and conventional steel spring. The main motive for this is to compare the load carrying capacity, stiffness and weight between the two springs. The main purpose is to detect the stresses and deflection produced by the leaf spring.
The dimension which are used to make conventional spring are also used to make composite leaf spring. The composite leaf spring are made of E Glass Epoxy laminate. The purpose of leaf spring is to absorb vertical vibration which are produced and the impact produced due to irregularities in the road and with the variation in the spring deflection it stores the potential energy as strain energy in the spring and then it is released slowly. As we have studied till now that materials having maximum strength and maximum module of elasticity in the longitudinal direction are best suitable material for leaf springs and since composites have these quality hence also suitable for making leaf spring. The objective is to compare the results produced by composite leaf spring using hand lay-up technique and conventional leaf spring. This technique used for manufacturing is an alternative and efficient technique as compared to filament winding technique. A detailed analysis over the leaf spring is done with the help of ANSYS software. Similarly a detailed study is done between both springs with respect to weight, cost, and strength. From the observed and calculated results it is seen that composite spring is lighter and more economical than conventional spring with the same dimensions for both the springs. It was seen that the weight reduced was around more than 80% from composite leaf spring with steel spring.

[M. Raghavedra et al 2012][12] This paper depicts framework and examination of overlaid composite mono leaf spring. Weight diminishing is presently the essential issue in auto organizations. In the present work, the estimations of a current mono steel leaf spring of a Maruti 800 explorer vehicle is taken for showing and examination of an overlaid composite mono leaf spring with three particular composite materials specifically, E-glass/Epoxy, S-glass/Epoxy and Carbon/Epoxy subjected to the same load as that of a steel spring. The arrangement limits were tensions and evasions. The three assorted composite mono leaf springs have been shown by considering uniform cross-section, with unidirectional fiber presentation plot for each lamina of an overlay. Static examination of a 3-D model has been performed using ANSYS 10.0. The focus of the present work is to arrange and examinations, of mono steel leaf spring moreover secured composite leaf spring made of three differing composite materials viz., E-glass/epoxy, S-glass/ epoxy and Carbon/epoxy composites. Secured composite leaf of four layers with uni-directional fiber presentation edge i.e., 00 is considered. A virtual model of both steel and secured mono composite leaf spring was made in Pro-E. Model is outside in ANSYS 10.0 for examination by applying common weight conditions. After investigation an examination is made between existing conventional steel leaf spring and overlaid mono composite leaf spring viz., e-glass/epoxy, s-glass/epoxy, and carbon/epoxy similarly as redirections and bothers, to pick the best one. A close study has been made between overlaid composite leaf spring and steel leaf spring with respect to weight, solidness and quality. By using a composite leaf spring for the same weight passing on point of confinement, there is a lessening in weight of 73%~80%, regular repeat of composite leaf springs are 27%~67% higher than steel leaf spring and 23~65% stiffer than the steel spring. Considering the results, it was construed that carbon/epoxy secured composite mono leaf spring has unrivaled quality and solidness and lesser in weight stood out from steel and other composite materials considered in this examination. From the results, it is viewed that the secured composite leaf spring is lighter and more proficient than the customary steel spring with near layout points of interest.

[Manas Patnaik et al 2012][13] This work is done on a mono explanatory leaf spring of a small scale loader truck, which has a stacking limit of 1 Tons. The demonstrating of the leaf spring has been carried out in CATIA V5 R20. Furthermore, for limited component examination the model was foreign in the static structural investigation workbench of CATIA V5 R20. The limited component investigation of the leaf spring has been done by at first discretizing the model and after that applying the applicable limit conditions. Max Von Mises push and Max Displacement are the yield parameters of this investigation. Keeping in mind the end goal to study the conduct of allegorical leaf spring, Design of analyses has been executed. Illustrative leaf spring ingests the vertical vibrations and effects because of street abnormalities by method for varieties in the spring redirection so that the potential vitality is put away in spring as strain vitality and afterward steadily discharged to look after solace. The limited component investigation (FEA) is a figuring procedure that is utilized to get rough answers for the limit esteem issues in building. It utilizes a numerical method called the limited component system (FEM). It is currently acknowledged by real commercial enterprises over the world and an organization that has the capacity confirm a proposed configuration will have the capacity to perform to the customer's details before assembling or development. The camber is expanded there is a reduction in the normal measure of dislodging. On the off chance that the eye separation is expanded there is an increment in the normal measure of dislodging. On the off chance that the camber is expanded there is an increment in the normal measure of von mises stress on the off chance that the eye separation is expanded there is an increment in the normal sum in von misses stress.

[Kumar Krishan et al 2012][14]As we know focused weights among the assembling associations are expanding step by step that is the reason the components which draw in generally clients are solace & cost. This work is comprises of Finite Element (FE) Analysis of mono steel leaf spring and a mono leaf spring made of composite materials i.e. Glass Reinforced Plastic (GRP) which is having high quality to weight degree. The target of this work with FEA is to look at the impact of material change on anxieties and weight of gathering. For this examination the material of leaf spring is supplanted from steel to composite material i.e. GRP. For FE Analysis mono leaf spring is demonstrated in CATIA and afterward investigated with ANSYS programming. FEA relies on real presumptions of the get together which goes about as data information. Glass Reinforced Plastics is composite material in which the volume part of glass fiber is 48%. It is amassed utilizing sewing apparatus to structure a unidirectional glass tape of consistent width. It comprises of 97% glass in longitudinal course & 3% in transverse bearing. Limited Element Analysis: An anxiety avoidance examination is performed utilizing limited component investigation (FEA). The complete methodology of examination has been carried out utilizing ANSYS-11. At the point when steel leaf spring is supplanted by composite material (GRP), the avoidance is diminished by 6.51%.The twisting stretch in the event of GRP Leaf spring is diminished by 83.64%.At the same time when contrasting steel & GRP leaf spring, there is a material sparing of 71.85% by weight.

[K. K. Jadhao et al 2011][15] The target of present study was to substitute material for leaf spring. In present study the material chose was glass fiber fortified plastic (GFRP) and the polyester pitch (NETPOL 1011) can be utilized which was more prudent this will lessen aggregate expense of composite leaf spring. A spring with steady width and thickness was manufactured by hand lay-up method which was extremely straightforward and conservative. The trials were directed on UTM and numerical examination was carried out by means of (FEA) utilizing. ANSYS programming. Hassles and avoidance results were confirmed for expository and exploratory results. To address the issues of common asset protection and vitality economy, car makers have been endeavoring to decrease the heaviness of vehicles as of late. The suspension spring is one of most vital framework in auto which diminish yank, vibration and ingest stuns amid riding. Fiber-strengthened polymers have been overwhelmingly produced for some applications, fundamentally on account of the potential for weight reserve funds. Different favorable circumstances of utilizing fiber-strengthened polymers rather than steel are: (a) the likelihood of decreasing commotion, vibrations and ride brutality because of their high damping elements; (b) the nonattendance of consumption issues, which means lower upkeep expenses; and (c) lower tooling expenses, which has ideal effect on the assembling expenses Springs are critical suspension components in autos, important to minimize the vertical vibrations, effects and knocks because of street regularities The conduct of steel leaf spring is nonlinear, moderately high weight, and change in strong hub edge because of weight exchange exceptionally amid cornering of vehicle, that will prompt over cow and directional insecurity under such circumstance it is extremely troublesome for driver to control vehicle, these are some imperfection of metallic leaf spring so considering vehicles improvement and significance of relative angle, for example, fuel utilization, weight, riding quality, and taking care of, so advancement of new material is essential in the car business. The goal of present work is to plan, manufacture and exploratory testing and examination of composite spring made up of E-glass fiber, cleaved strands tangle and epoxy pitch with consistent width and thickness all through its length. In the trial examination the relative testing of mono composite leaf spring and the steel leaf spring are taken. The diversion or twisting tests of both the spring for similar study is tackled the general testing machine. These outcomes are additionally contrasted and FEA. The heaviness of the leaf spring is decreased extensively around 85 % by supplanting steel leaf spring with composite leaf spring. Along these lines, the goal of diminishing the unsprung mass is accomplished to some degree. Likewise, the anxieties in the composite leaf spring are much lower than that of the steel spring**.**

[V. K. Aher et al 2012][16] The leaf spring is generally utilized as a part of vehicles and one of the parts of suspension framework. It needs to have incredible weakness life. When in doubt, the leaf spring must be viewed as a wellbeing part as disappointment could prompt serious mishaps. The reason for this paper is to foresee the weariness life of semi-circular steel leaf spring alongside systematic anxiety and avoidance figuring's. This present work portrays static and exhaustion investigation of a changed steel leaf spring of a light business vehicle (LCV). The measurements of an adjusted leaf spring of a LCV are taken and are confirmed by configuration computations Multi leaf spring was demonstrated utilizing business programming and all the particulars were in like manner took after the applicable drawing standard. The spring geometry comprises of expert leaves and graduated clears out. As a preparatory study here, a few suspicions have been made i.e. the picked material was homogeneous, the frictional impact has not been considered, shackle and bramble was not demonstrated, to decrease the multifaceted nature of recreation. Shackle and bushing just exhibited by limit condition. The entire gathering is preprocessed in ALTAIR Hyper mesh v10. The iges record is imported to Hyper mesh, wherein limited component demonstrating is executed. The non-direct examination is finished leaf spring in its level condition by determining the heap regarding "Newton" and different measurements by 'mm'. The imperatives connected are multi point requirements. The heap is connected consistently on the casing structure. The examination document is connected to the solver. In the wake of comprehending the model, the outcomes can be seen to the craved condition. The weariness life expectation is performed in view of limited component investigation and exhaustion life recreation strategy. FEM gives the forecast of basic region from the perspective of static stacking. The consequences of non-straight static examination of 2D model of the leaf spring utilizing the business solver and diagnostic results shows better relationship. The solidness of the leaf spring is examined by plotting burden versus redirection bend for entire working burden range which demonstrates the direct relationship. Utilizing the steady abundance stacking, the weariness harm and life of the spring has been anticipated. From the harm form, the most elevated harm quality is in worthy reach. This study will help to see more the conduct of the spring and give data for the producer to enhance the weariness life of the spring utilizing CAE devices. It can help to diminish cost and times in innovative work of new item.

[**Loganathan P et al 2015][17]**Decreasing weight while expanding or keeping up quality of items is getting the chance to be exceedingly essential examination issue in this advanced world. Composite materials are one of the material families which are drawing in specialists and being arrangements of such issue. In this work decreasing weight of vehicles and expanding or keeping up the quality of their extra parts is considered. As leaf spring contributes impressive measure of weight to the vehicle and needs to be sufficiently solid, a solitary E-glass/Epoxy leaf spring is composed and mimicked after the configuration principles of the composite materials considering static stacking just. Limited Element investigation instrument offer the enormous favorable circumstances of empowering outline groups to consider practically any demonstrating alternative without acquiring the cost connected with assembling and machine time. The capacity to attempt new outlines or ideas on the PC gives the chance to wipe out issues before starting generation. The leaf spring ought to assimilate the vertical vibration and effects because of street anomalies by method for vibrations in the spring redirection so that the potential. Static examination of 3-D model of traditional leaf spring is likewise performed utilizing Pro/E 4.0 and contrasted and trial results. A relative study has been made in the middle of steel and composite leaf spring concerning quality and weight. From the outcomes, it is watched that the composite leaf spring is lighter and more conservative than the ordinary steel spring with comparative configuration details. Contrasted with steel spring, the composite leaf spring is found to have 67.35% lesser anxiety than that of existing steel leaf spring. A weight diminishment of 76.4% is attained to by utilizing upgraded composite leaf spring. E-glass/epoxy composite leaf spring can be recommended for supplanting the steel leaf spring from anxiety and solidness perspective.

Chapter 5

5 Methodology

This chapter shows the mathematical relation's used over a classical laminate theory and for further analysis over composite material.

Hooke's Law: Generalized Hooke's Law for an orthotropic material is given by:-

$\{ \sigma \} = [Q]*\{ \varepsilon \}$

Where S is the stress produced while Q and € are the stiffness of the material and strain matrix respectively.

For the Plane Stress Condition we can write for each layer of the laminates

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \gamma_{xz} \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} Q11 & Q12 & 0 & 0 & 0 \\ Q12 & Q22 & 0 & 0 & 0 \\ 0 & 0 & Q44 & 0 & 0 \\ 0 & 0 & 0 & Q55 & 0 \\ 0 & 0 & 0 & 0 & Q66 \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{xz} \\ \varepsilon_{xy} \end{Bmatrix}$$

Where $\{ \sigma \}$ represents the stress matrix, [Q] shows the stiffness matrix of the composite material and $\{ \varepsilon \}$ is the strain matrix.

5.1 Relationship between the Engineering Constants and the Elements of Stiffness Matrix

$Q_{11} = E_1 / (1-\upsilon_{12}*\upsilon_{21})$

$Q_{22} = E_2 / (1-\upsilon_{12}*\upsilon_{21})$

$Q_{12} = E_1*\upsilon_{12} / (1-\upsilon_{12}*\upsilon_{12})$

$Q_{44}=G_{23}$

$Q_{55}= G_{13}$

$Q_{66}= G_{12}$

Here E_1 and E_2 are the elastic modulus of the material and υ_{12} and υ_{21} are the poisons ratio for the composite material and the transformed stiffness matrix can be written as

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \sigma_{zz} \\ \gamma_{xz} \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} \bar{Q}11 & \bar{Q}12 & 0 & 0 & 0 \\ \bar{Q}12 & \bar{Q}22 & 0 & 0 & 0 \\ 0 & 0 & \bar{Q}44 & 0 & 0 \\ 0 & 0 & 0 & \bar{Q}55 & 0 \\ 0 & 0 & 0 & 0 & \bar{Q}66 \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \varepsilon_{zz} \\ \varepsilon_{xz} \\ \varepsilon_{xy} \end{Bmatrix}$$

And for finding the values of [Q̄] a certain relation is to be followed which is given as

[Q̄] = $[T]^{-1}$ [Q] $[T]^{-1}$ where [T] matrix represents the stress transformation matrix and is given by

$$[T]=\begin{bmatrix} m^2 & n^2 & mn \\ n^2 & m^2 & -mn \\ -2mn & 2mn & m^2-n^2 \end{bmatrix}$$

Where m represents the cos (θ) and n is the sin (θ) where (θ) is the orientation angles of the fibers in the composite material.

5.2 Steps Require For the Laminate Analysis

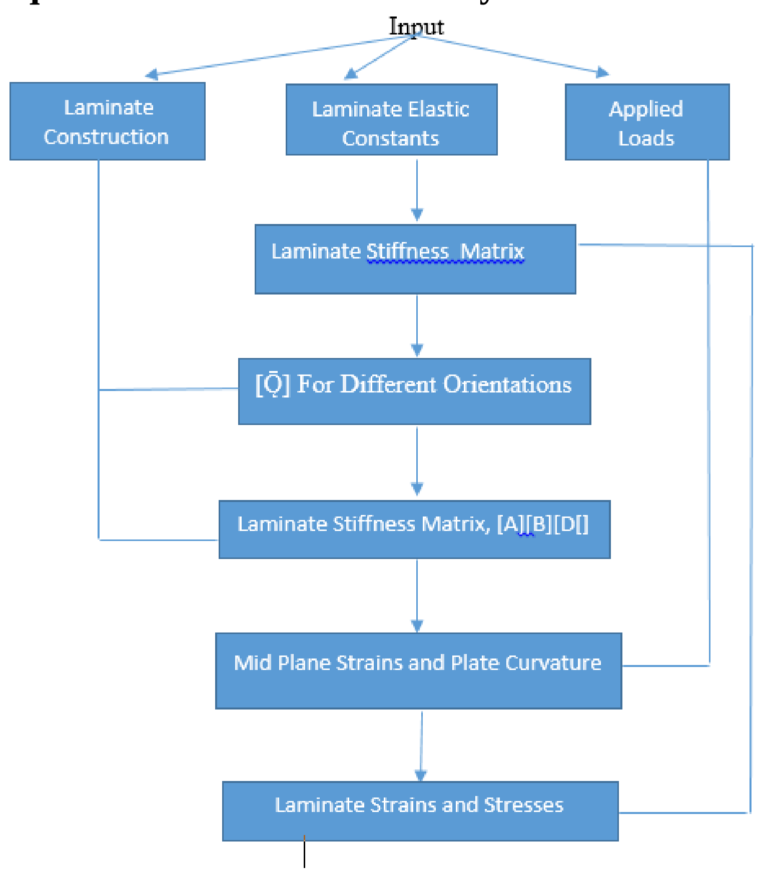

Figure 5.1 Flowchart for Analysis of Laminate

Step 1: Laminate Stiffness Matrix can be calculated with the help of Laminate Elastic Constants in which Poisson's ratio in transverse and longitudinal direction, Young's Modulus of Elasticity in Transverse and Longitudinal direction are known along with the Modulus of Rigidity for the specific composite material.

Step 2: For the reduced transformed matrix of the ply in various orientations can be calculated as follows.

$\bar{Q}_{11}$= $Q_{11}\cos^4\theta + Q_{22}\sin^4\theta + 2(Q_{12}+2Q_{66})\sin^2\theta\cos^2\theta$

$\bar{Q}_{22}$= $Q_{11}\sin^4\theta + Q_{22}\cos^4\theta + 2(Q_{12}+2Q_{66})\sin^2\theta\cos^2\theta$

$\bar{Q}_{12}$= $(Q_{11}+Q_{22}-4Q_{66})\sin^2\theta\cos^2\theta + Q_{12}(\sin^4\theta+\cos^4\theta)$

$\bar{Q}_{66}$= $(Q_{11}+Q_{22}-2Q_{12}-2Q_{66})\sin^2\theta\cos^2\theta + Q_{66}(\sin^4\theta+\cos^4\theta)$

$\bar{Q}_{16}$= $(Q_{11}-Q_{12}-2Q_{66})\sin\theta\cos^3\theta - (Q_{11}-Q_{12}-2Q_{66})\sin^3\theta\cos\theta$

$\bar{Q}_{26}$= $(Q_{11}-Q_{12}-2Q_{66})\sin^3\theta\cos\theta - (Q_{11}-Q_{12}-2Q_{66})\sin\theta\cos^3\theta$

From the above given equations we can clearly see that we can calculate the reduced stiffness matrix for different orientations of the laminate.

Step 3: Now we have to calculate [A], [B], [D] which are known as Extensional Stiffness Matrix, Coupling Stiffness Matrix, and Bending Stiffness Matrix respectively.

For calculation the A B D Matrix

$A_{ij}= \sum_{k=0}^{n}((\bar{Q}_{ij})_k(h_k - h_{k-1})$

$B_{ij}= \frac{1}{2}\sum_{k=0}^{n}(\bar{Q}_{ij})_k\,(h_k^2 - h_{k-1}^2)$

$D_{ij}= \frac{1}{3}\sum_{k=0}^{n}(\bar{Q}_{ij})_k\,(h_k^3 - h_{k-1}^3)$

$$\begin{Bmatrix}\varepsilon_X^0\\ \varepsilon_Y^0\\ \gamma_{XY}^0\end{Bmatrix}=\begin{bmatrix}A_{11}\ A_{12}\ A_{16}\\ A_{12}\ A_{22}\ A_{16}\\ A_{16}\ A_{26}\ A_{66}\end{bmatrix}\begin{Bmatrix}N_x\\ N_y\\ N_{xy}\end{Bmatrix}+\begin{bmatrix}B_{11}\ B_{12}\ B_{16}\\ B_{12}\ B_{22}\ B_{16}\\ B_{16}\ B_{26}\ B_{66}\end{bmatrix}\begin{Bmatrix}M_x\\ M_y\\ M_{xy}\end{Bmatrix}$$

$$\begin{Bmatrix}k_x\\ k_y\\ k_{xy}\end{Bmatrix}=\begin{bmatrix}B_{11}\ B_{12}\ B_{16}\\ B_{12}\ B_{22}\ B_{16}\\ B_{16}\ B_{26}\ B_{66}\end{bmatrix}\begin{Bmatrix}N_x\\ N_y\\ N_{xy}\end{Bmatrix}+\begin{bmatrix}D_{11}\ D_{12}\ D_{16}\\ D_{12}\ D_{22}\ D_{16}\\ D_{16}\ D_{26}\ D_{66}\end{bmatrix}\begin{Bmatrix}M_x\\ M_y\\ M_{xy}\end{Bmatrix}$$

From the above equations we can calculate the values of mid plane stresses and plate curvature.

Step 4: Now we have to calculate the mid plane strains and the plate curvature when a certain load is being applied over any direction of the body.

$$\begin{Bmatrix}\varepsilon^0\\ k\end{Bmatrix} = \begin{bmatrix}A'\ B'\\ B'\ D'\end{bmatrix}\begin{Bmatrix}N\\ M\end{Bmatrix}$$

Where

$$[A'] = [A^*] - [B^*][D^{*^{-1}}][B']$$

$$[B'] = [B^*][D^{*^{-1}}]$$

$$[D'] = [D^{*^{-1}}]$$

Where $[A^*] = [A^{-1}]$

$$[B^*] = -[A^{-1}][B]$$

$$[D^*] = [D] - [B][A^{-1}][B]$$

Step 5: Now we need to calculate the laminate strains which can be obtained from this relations

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{Bmatrix} \varepsilon_X^0 \\ \varepsilon_Y^0 \\ \gamma_{XY}^0 \end{Bmatrix} + z \begin{Bmatrix} k_x \\ k_y \\ k_{xy} \end{Bmatrix}$$

Step 6: Now we need to transform the laminate strains form arbitrary directions to the longitudinal and transverse directions which are done with the help of these relations

$$\begin{Bmatrix} \varepsilon_L \\ \varepsilon_T \\ \gamma_{LT} \end{Bmatrix} = \begin{bmatrix} m^2 & n^2 & mn \\ n^2 & m^2 & -mn \\ -2mn & 2mn & m^2 - n^2 \end{bmatrix} \begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix}$$

Step 7: The final step for the laminate analysis is by calculating the stresses produced in the laminate

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{12} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_L \\ \varepsilon_T \\ \gamma_{LT} \end{Bmatrix}$$

Above mentioned steps are used for the calculation for stresses and strains produced in the laminate

The above mentioned steps are being used in the MATLAB for calculating the lamiane stresses and strains which are being produced in the laminate.

5.3 Specification of the problem

The fundamental intention of this work is to plan the Carbon Epoxy composite leaf spring for car suspension framework and break down it. This is carried out to attain to specific conditions, for example, to supplant the customary steel spring with carbon epoxy composite leaf spring and to accomplish weight diminishment in the suspension framework.

A virtual model of both steel and mono composite leaf spring is displayed in ANSYS 14.0 and an investigation is carried out by applying ordinary burden condition. After the examination a correlation is carried out between traditional steel spring and composite leaf spring while having avoidance and hassles as its requirements.

5.4 Specification of the Existing Leaf Spring

5.4.1 Physical Properties [18]

S.No.	Parameters	Values
1.	Young's Modulus of Elasticity	$2.1*10^5$ N/mm^2
2.	Poisson's Ratio	0.266
3.	BHN	400-425
4.	Upper Tensile Strength	1272 MPa
5.	Yield Tensile Strength	1158 MPa
6.	Density	0.00000785kg/mm^3

Table 5. 1 Mechanical Data

5.4.2 Chemical Composition

S.No.	Parameters	Percentage
1.	Material	Spring Steel(EN45A)
2.	C	0.58-0.65%
3.	Si	1.75-2.10%
4.	Mn	0.80-1.00%
5.	S	0.015%
6.	P	0.035%

Table 5. 2 Chemical Data

5.5 Specification of the Composite Leaf Spring [19]

S.No	Parameters	Value
1.	Material	Carbon-Epoxy
2.	Tensile Strength	1841 N/mm^2
3.	Young's Modulus of Leaf Spring	1.23e5 N/mm^2
4.	Total Length of Spring(Eye to Eye)	965 mm
5.	Free Chamber At No Load	110 mm
6.	No of full length leaves	01
7.	Thickness of leaves	20 mm
8.	Width of Leaf	35 mm

9.	Maximum Load on Spring	3400 N
10.	Spring Weigth	2.46 Kg

Table 5. 3 Specification of the Composite Leaf Spring

5.6 Values Used For Carbon Epoxy Composite Material

S.No	Parameters	Value
1.	E_1	177e3 MPa
2.	E_2	10.6e3 MPa
3.	G_{12}	7.20 MPa
4.	υ_{21}	0.02
5.	υ_{12}	0.27

Table 5. 4 Value of Carbon Epoxy Material

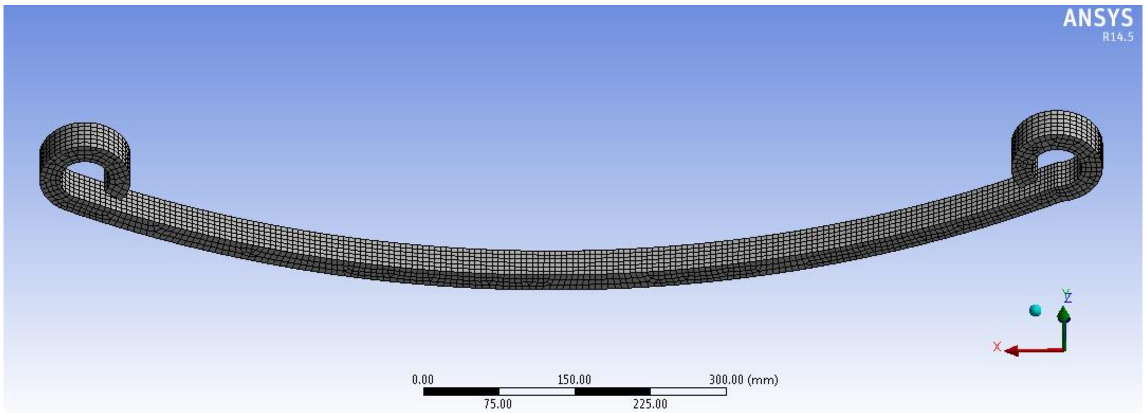

Figure 5. 2 Meshed Model for Composite Leaf Spring

From the above shown figure we see that the meshing of the composite leaf spring with which we can determine the node and the element number for determining the value at any element over the model.

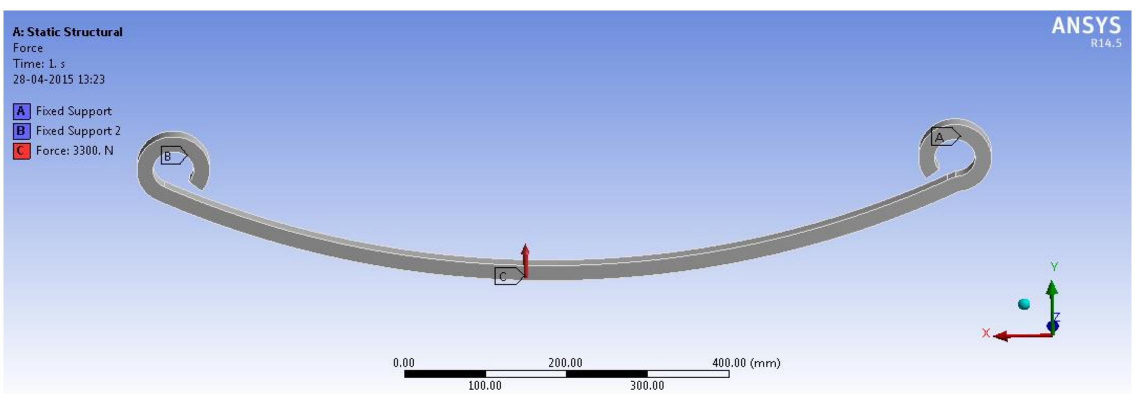

Figure 5. 3 Boundary Conditions

The above shown figure represents the boundary conditions applied in the Y Direction of the composite leaf spring as well as in the conventional steel spring. While both the eyes for both springs are considered to be as fixed supports.

Chapter 6

6 Results and Discussion

6.1 When tested over Conventional Steel Spring made of EN45A

6.1.1 Total Deformation at different Loads

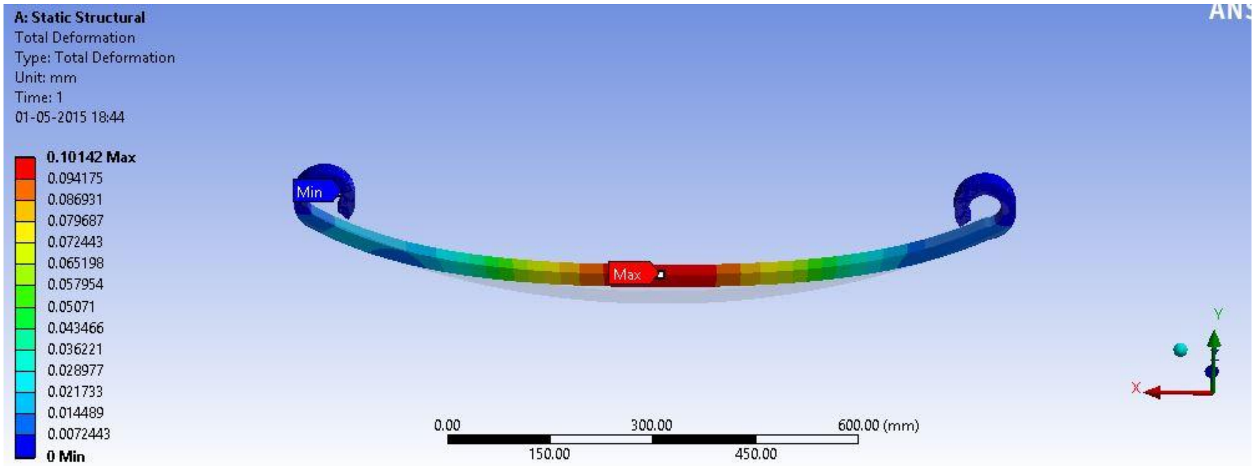

Figure 6. 1 Deformation At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the total deformation produced in the conventional steel spring and we see that maximum deformation produced is 0.10142 mm and minimum is 0mm.

6.1.2 Equivalent Stress under Different Loads

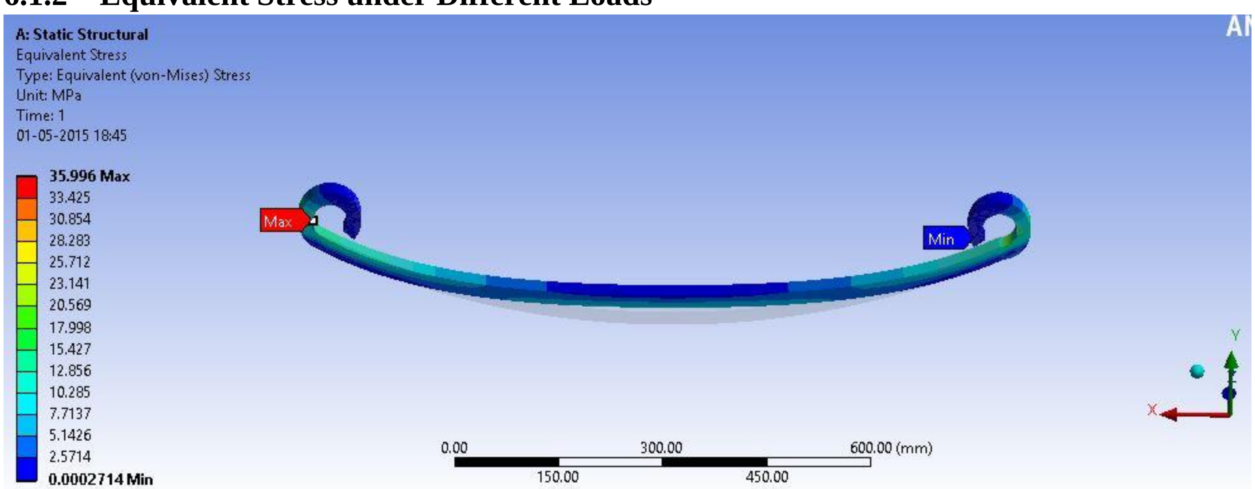

Figure 6. 2 Equivalent Stress At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent (von-mises)

Stress being produced in the conventional steel spring and we see that maximum stress produced is 35.996 MPa and minimum is 0.0002714MPa.

6.1.3 Equivalent Strain at Different Loads

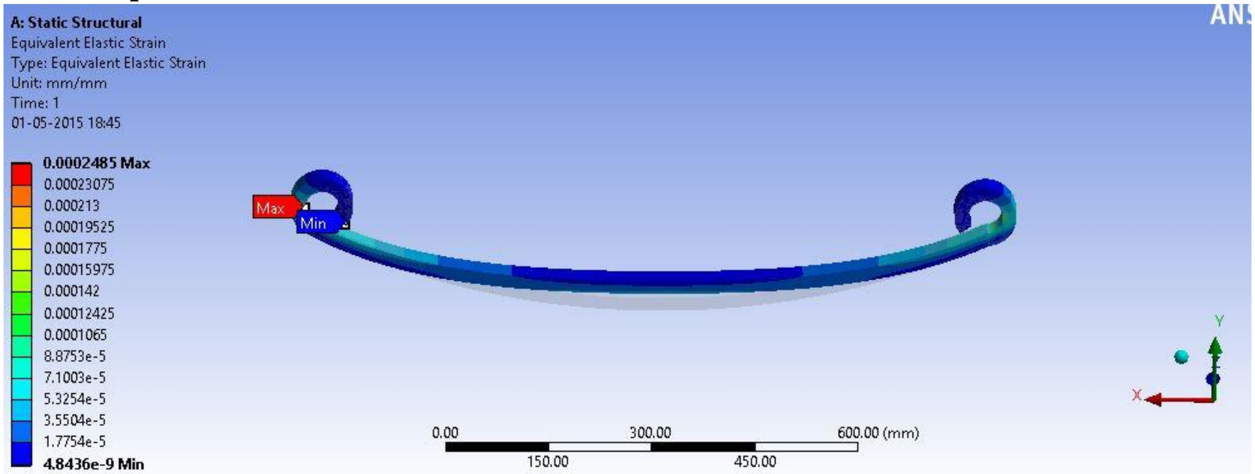

Figure 6. 3 Equivalent Strain At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent Elastic Strain being produced in the conventional steel spring and we see that maximum strain produced is 0.0002485 and minimum is 4.8436e-9.

6.2 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 0^0

6.2.1 Total Deformation at different Loads

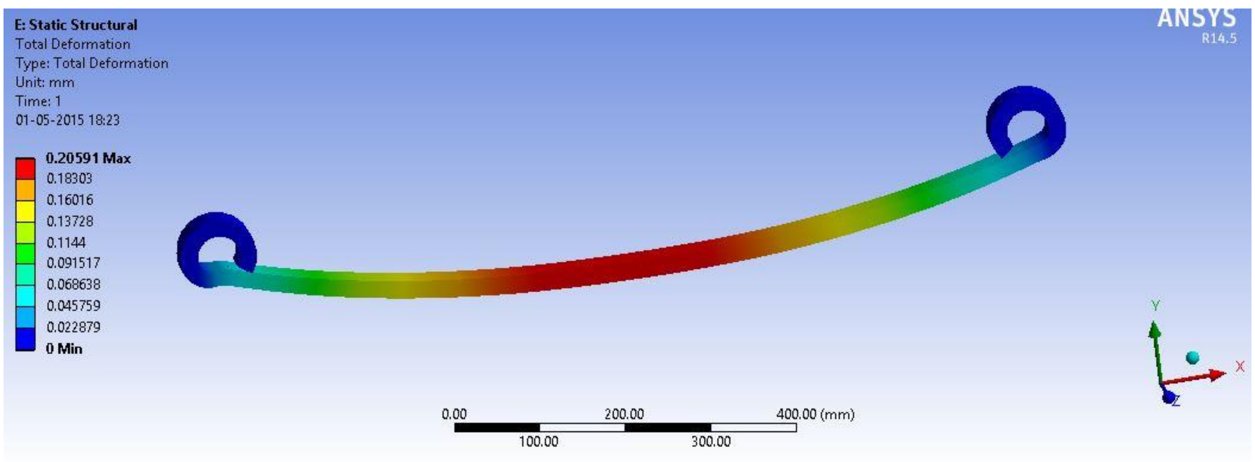

Figure 6. 4 Deformation at 3300N at 0 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the total deformation produced in the composite leaf spring and we see that maximum deformation produced is 0.20591mm and minimum is 0mm.

6.2.2 Equivalent Stress under Different Loads

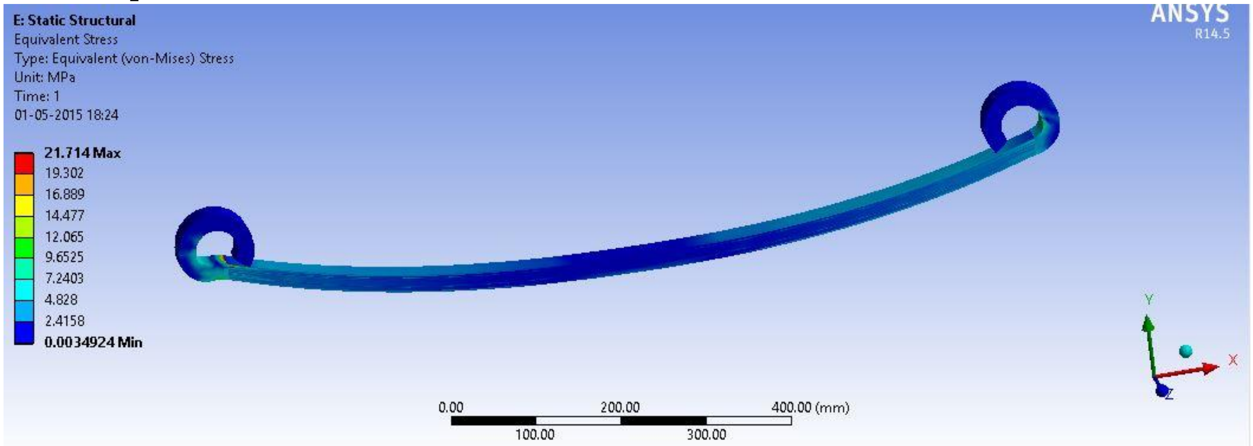

Figure 6. 5 Equivalent Stress at 3300N at 0 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent (von-mises) Stress produced in the composite leaf spring and we see that maximum stress produced is 21.714 MPa and minimum is 0.0034924MPa.

6.2.3 Equivalent Strain at Different Loads

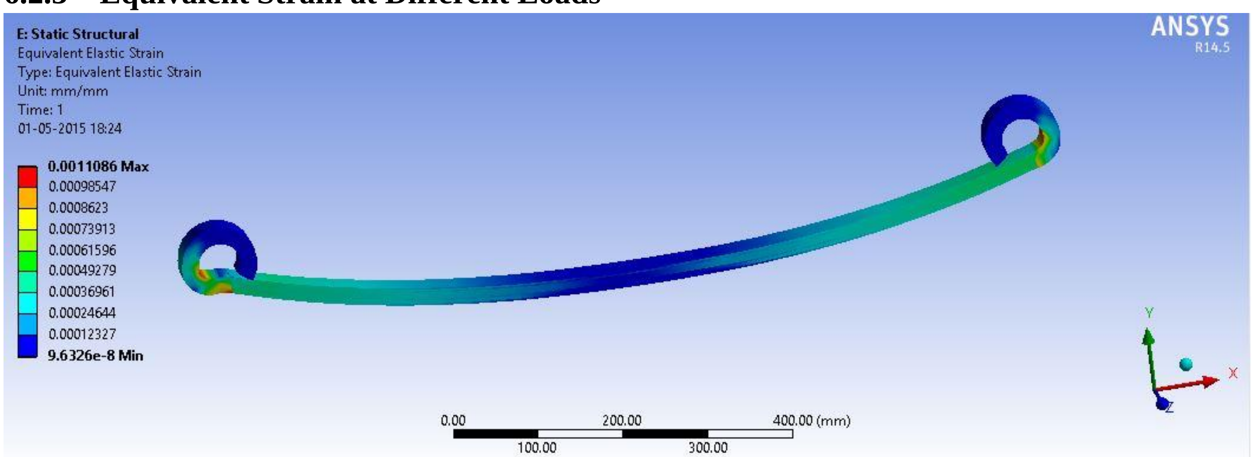

Figure 6. 6 Equivalent Strain at 3300N at 0 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent Elastic Strain produced in the composite leaf spring and we see that maximum strain produced is 0.0011086 and minimum is 9.6326e-8.

6.3 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 30^0

6.3.1 Total Deformation at different Loads

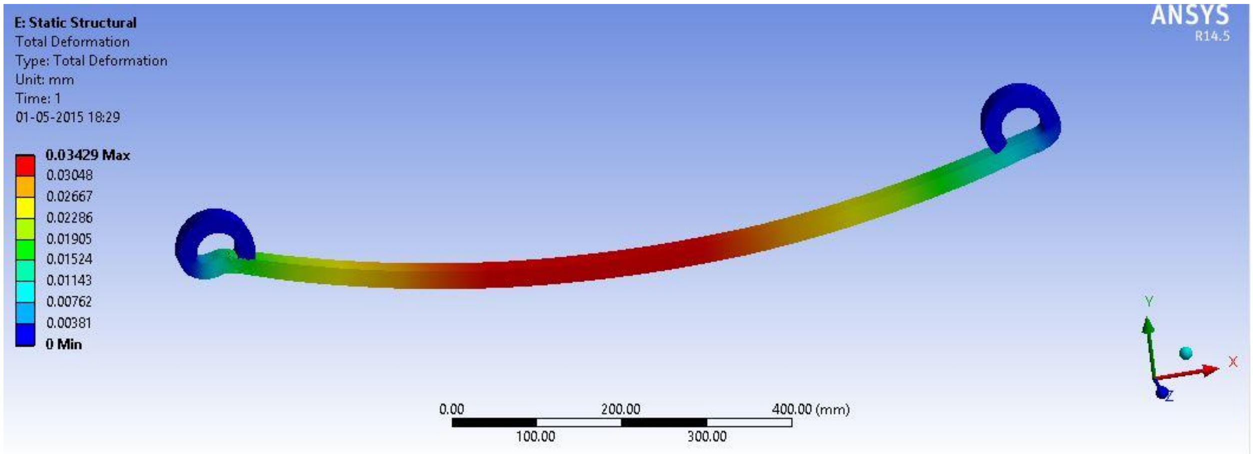

Figure 6. 7 Deformation at load 3300N at 30 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the total deformation produced in the composite leaf spring and we see that maximum deformation produced is 0.03429 mm and minimum is 0mm.

6.3.2 Equivalent Stress under Different Loads

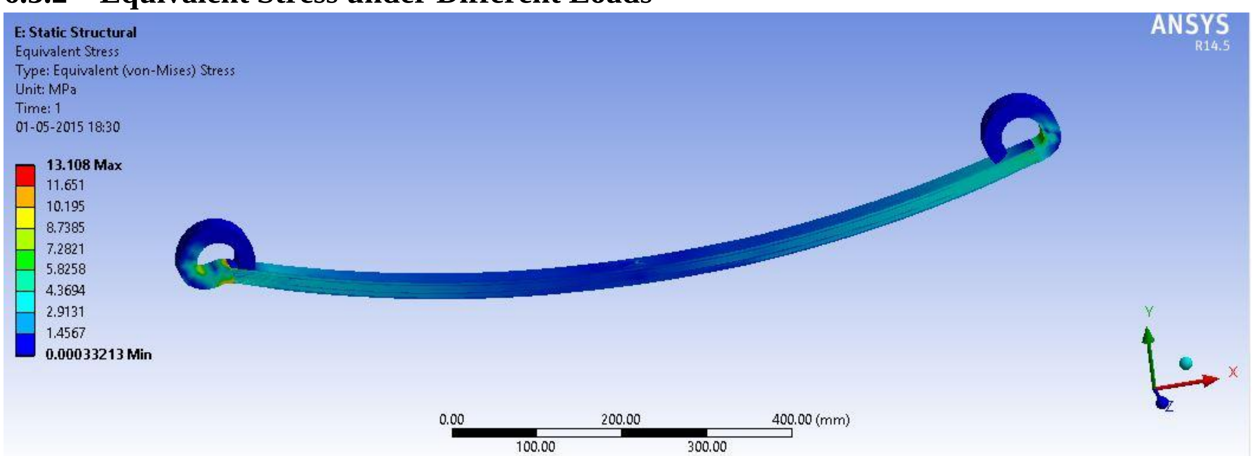

Figure 6. 8 Equivalent Stress at load 3300N at 30 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent (von-mises) Stress produced in the composite leaf spring and we see that maximum stress produced is 13.108 MPa and minimum is 0.00033213 MPa.

6.3.3 Equivalent Strain under Different Loads

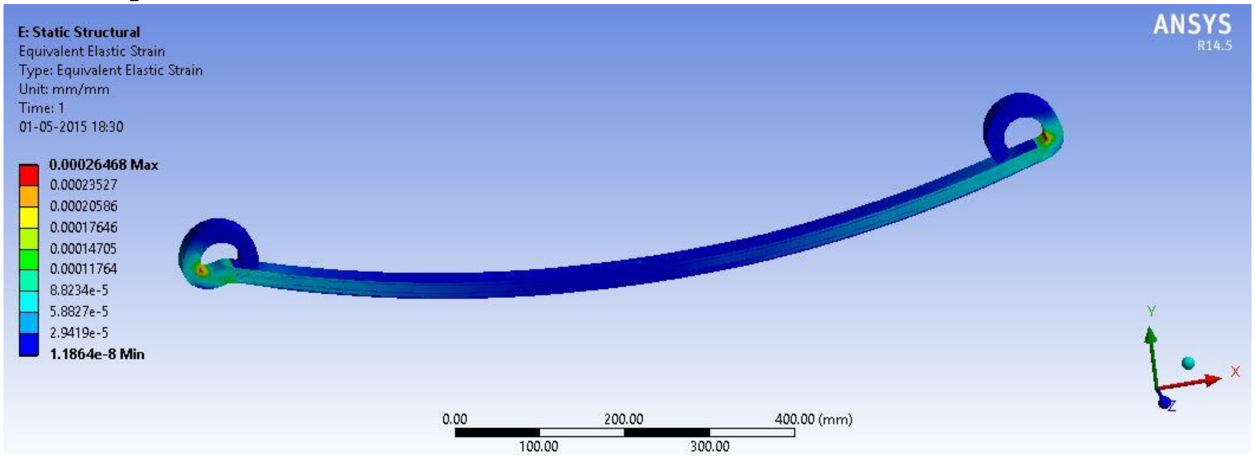

Figure 6. 9 Equivalent Strain at load 3300N at 30 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent Elastic Strain produced in the composite leaf spring and we see that maximum deformation strain is 0.00026468 and minimum is 1.1864e-8.

6.4 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 45^0

6.4.1 Total Deformation at different Loads

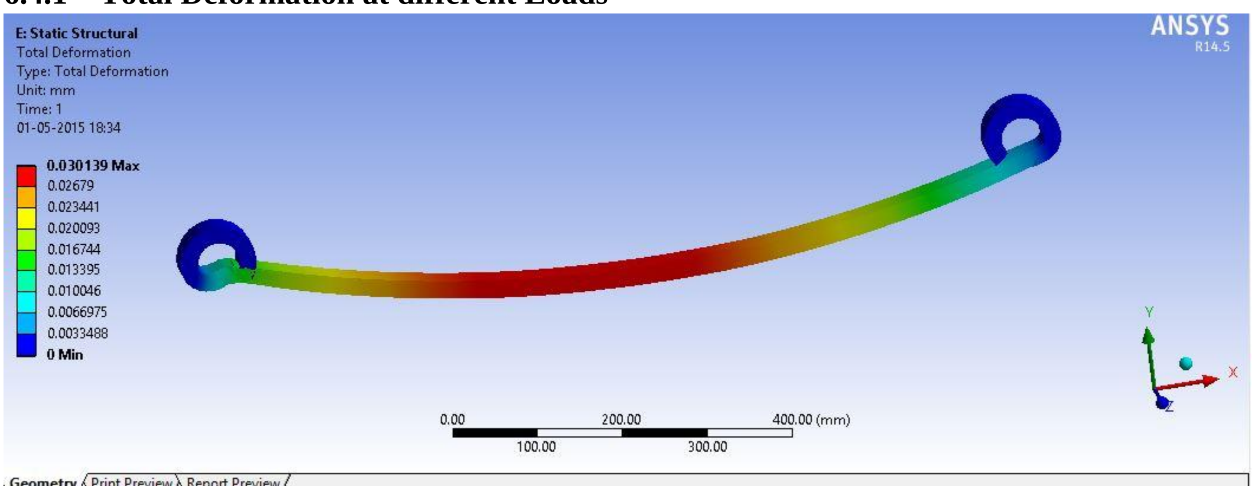

Figure 6. 10 Deformation at load 3300N at 45 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the total deformation produced in the composite leaf spring and we see that maximum deformation produced is 0.030139 mm and minimum is 0 mm.

6.4.2 Equivalent Stress under Different Loads

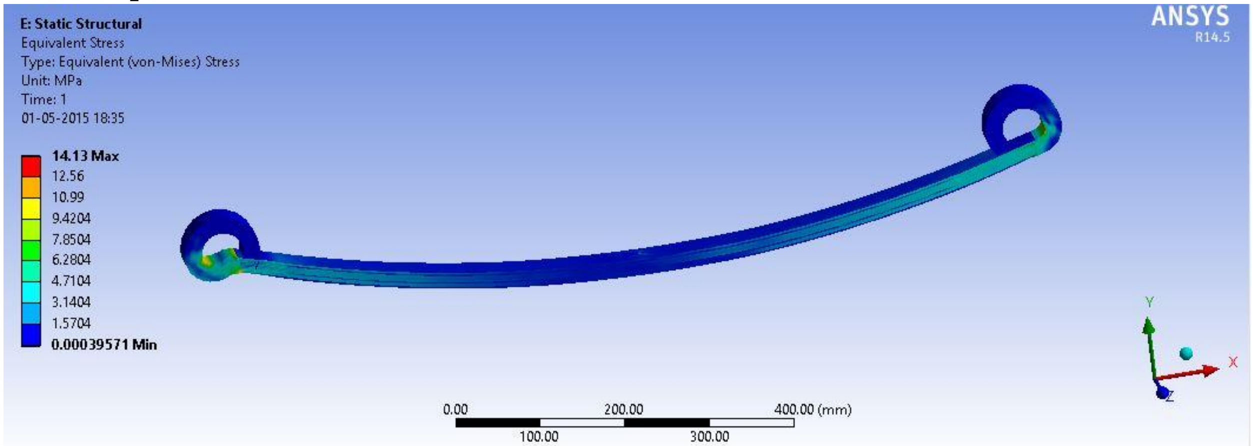

Figure 6. 11 Equivalent Stress at 3300N at 45 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent (von-mises) Stress produced in the composite leaf spring and we see that maximum stress produced is 14.13MPa and minimum is 0.00039571MPa.

6.4.3 Equivalent Strain under Different Loads

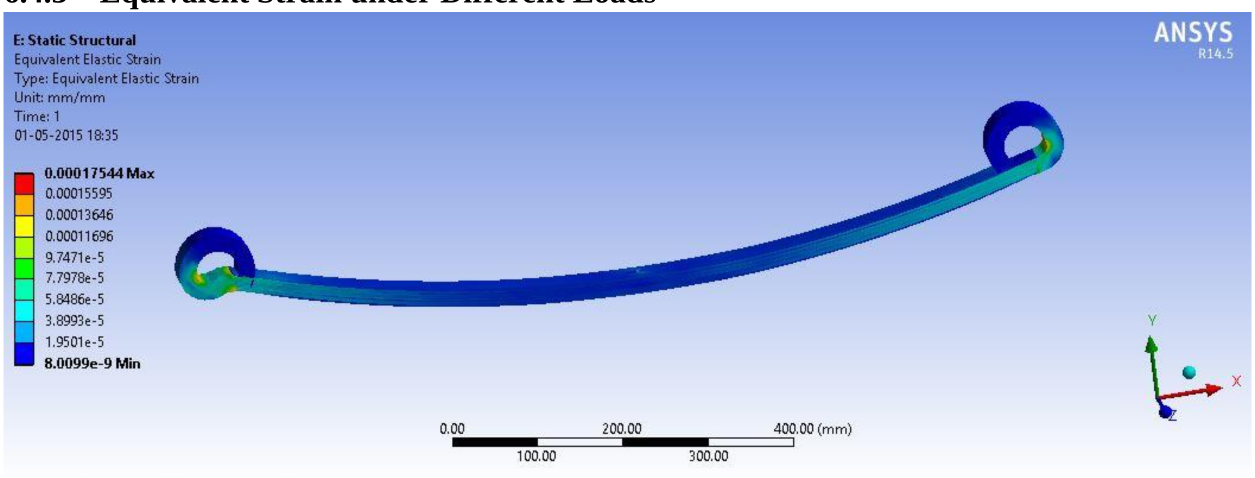

Figure 6. 12 Equivalent Strain at 3300N at 45 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent Elastic Strain produced in the composite leaf spring and we see that maximum strain produced is 0.00017544 and minimum is 8.0099e-9.

6.5 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 90^0

6.5.1 Total Deformation at different Loads

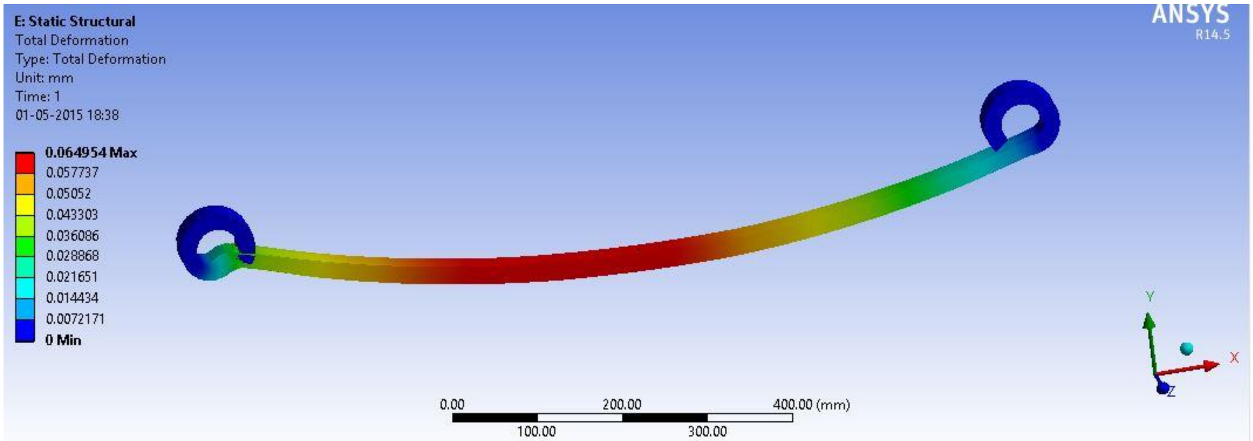

Figure 6. 13 Deformation at 3300N at 90 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the total deformation produced in the composite leaf spring and we see that maximum deformation produced is 0.064954 mm and minimum is 0 mm.

6.5.2 Equivalent Stress under Different Loads

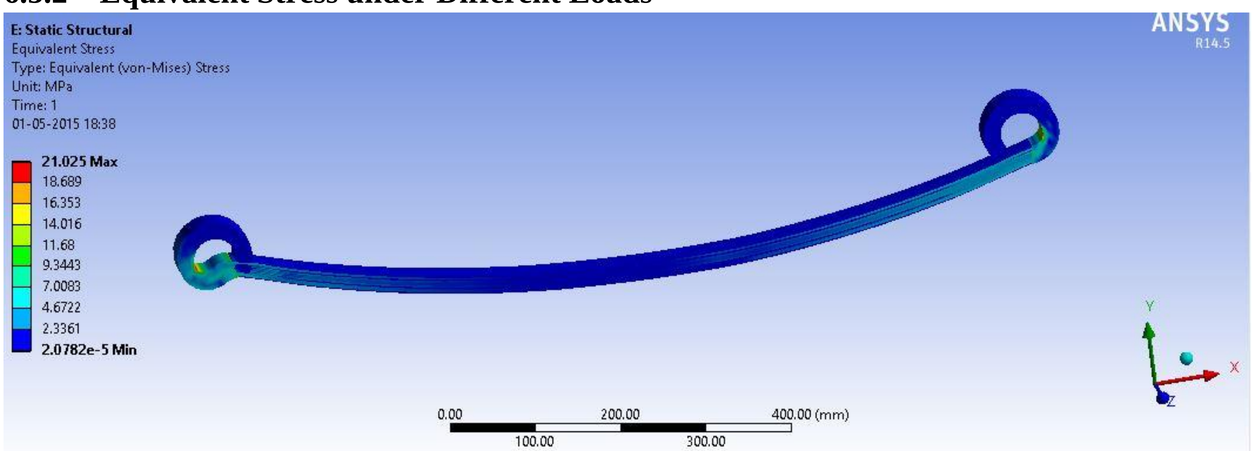

Figure 6. 14 Equivalent Stress at 3300N at 90 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent (von-mises) Stress produced in the composite leaf spring and we see that maximum stress produced is 21.025 MPa and minimum is 2.0782e-5 MPa.

6.5.3 Equivalent Strain under Different Loads

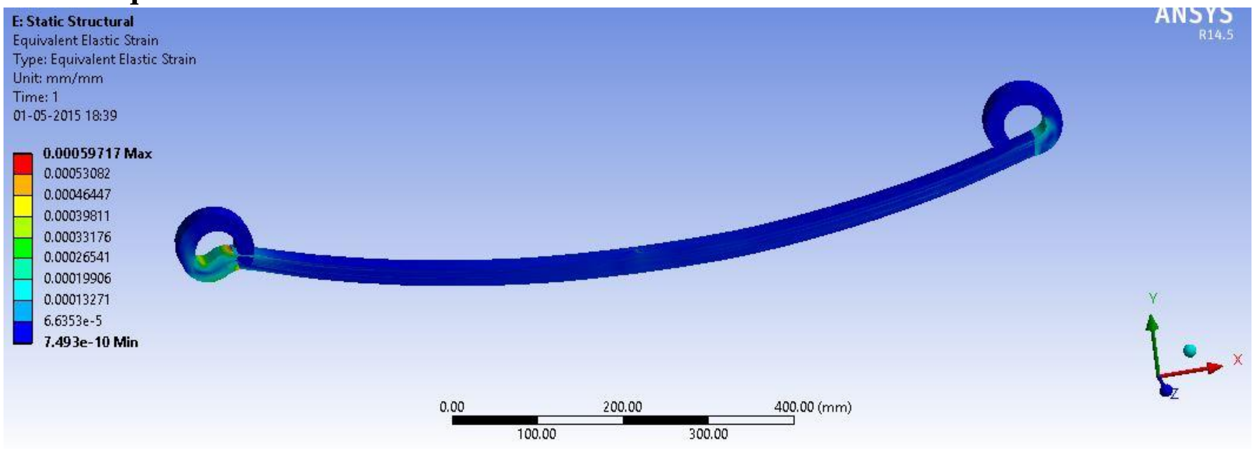

Figure 6. 15 Equivalent Strain at 3300N at 90 Degree

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Equivalent Elastic Strain produced in the composite leaf spring and we see that maximum strain produced is 0.00059717 and minimum is 7.493e-10.

6.6 When Tested over Conventional Steel Spring made of EN45A

6.6.1 Deformation at different loads 3300N

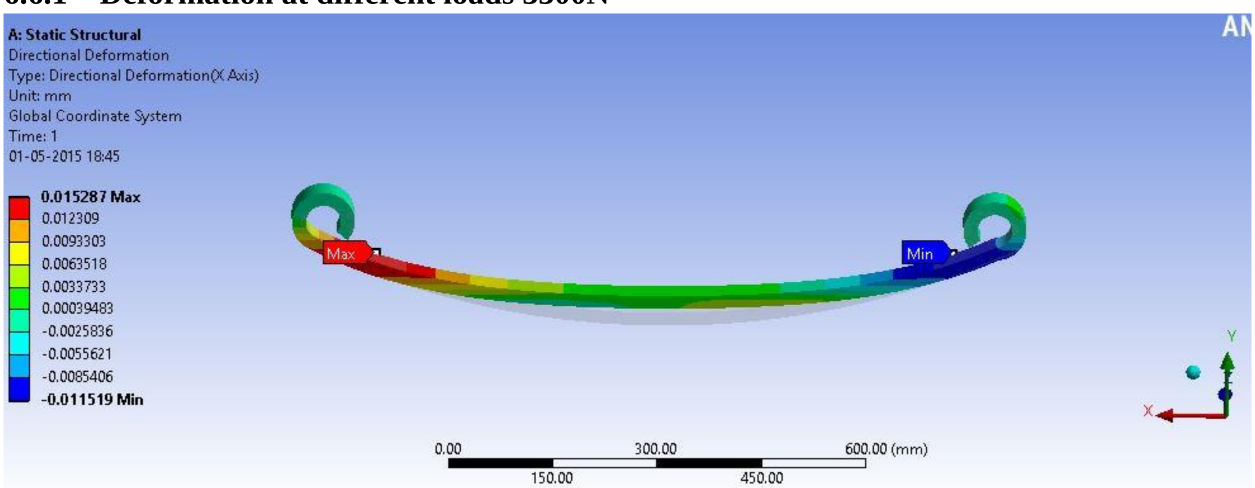

Figure 6. 16 Deformation in the X-Direction At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the X direction of the conventional steel spring and we see that maximum deformation produced is 0.015287mm and minimum is -0.011519 mm.

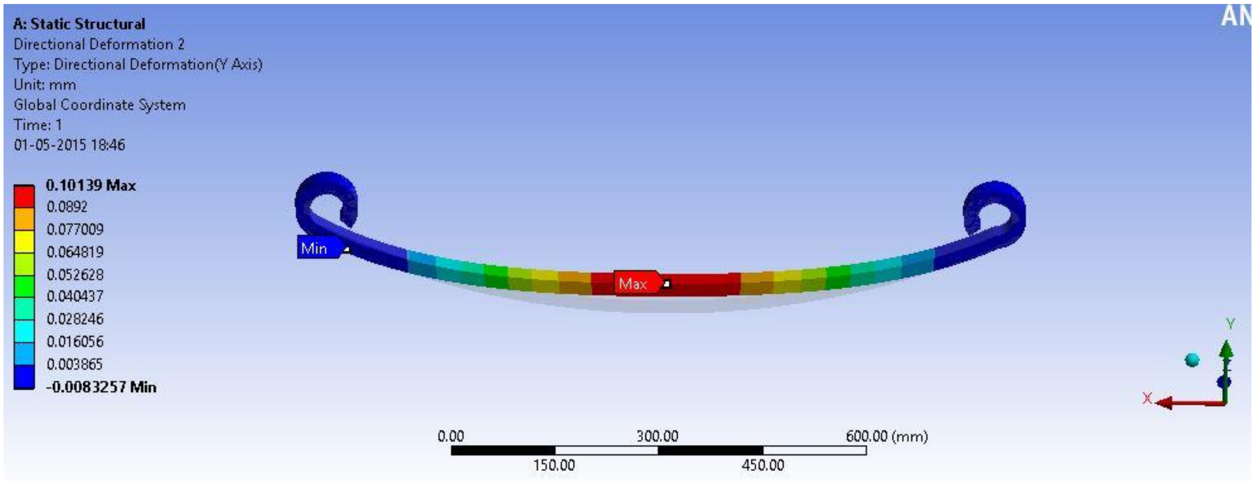

Figure 6. 17 Deformation in the Y-Direction At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Y direction of the conventional steel spring and we see that maximum deformation produced is 0.10139 mm and minimum is -0.0083257mm.

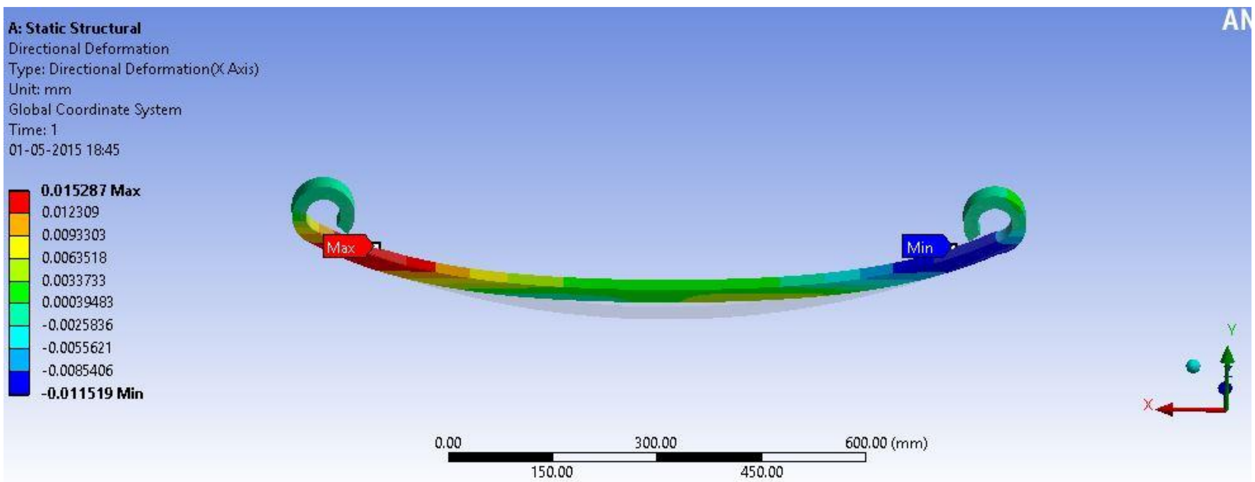

Figure 6. 18 Deformation in the Z-Direction At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Z direction of the conventional steel spring and we see that maximum deformation produced is 0.015287 mm and minimum is -0.011519 mm.

6.6.2 Principal Strain at different loads 3300N

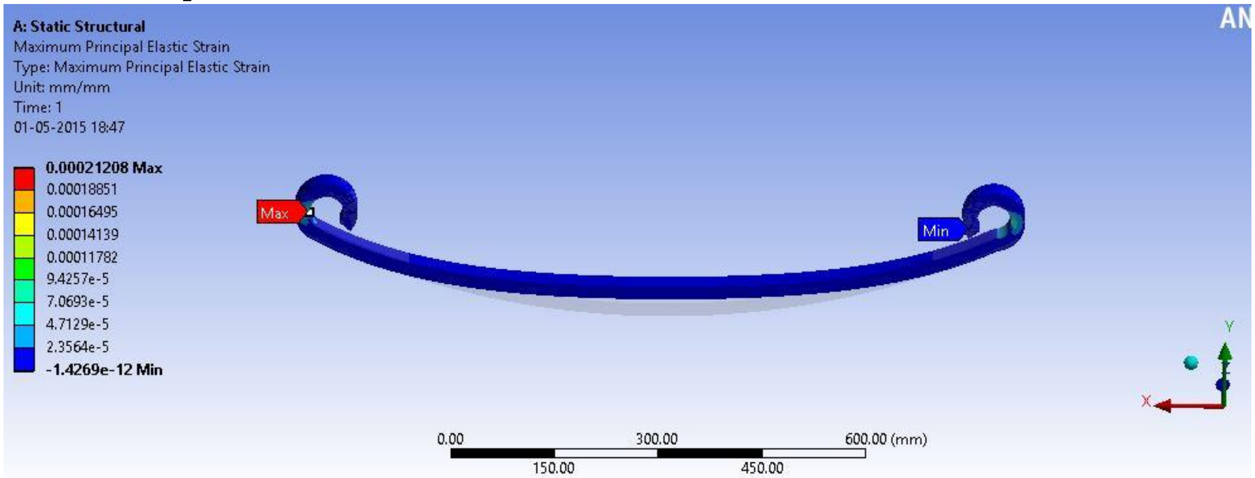

Figure 6. 19 Maximum Principal Strain At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Elastic Strain being produced in the conventional steel spring and we see that maximum strain produced is 0.00021208 and minimum is -1.4269e-12.

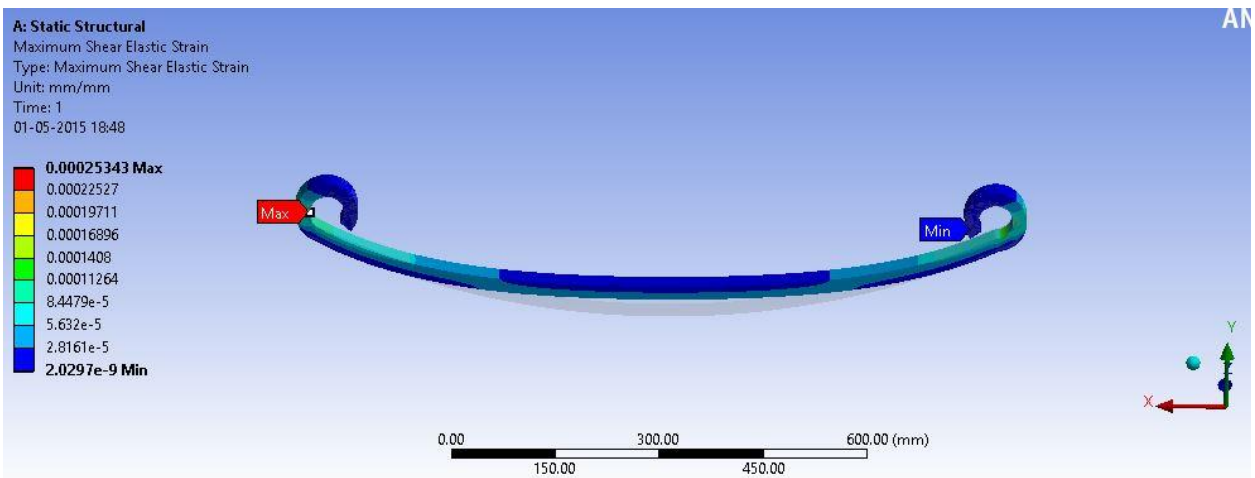

Figure 6. 20 Maximum Shear Strain At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Elastic Strain being produced in the conventional steel spring and we see that maximum strain produced is 0.00025343 and minimum is 2.0297e-9.

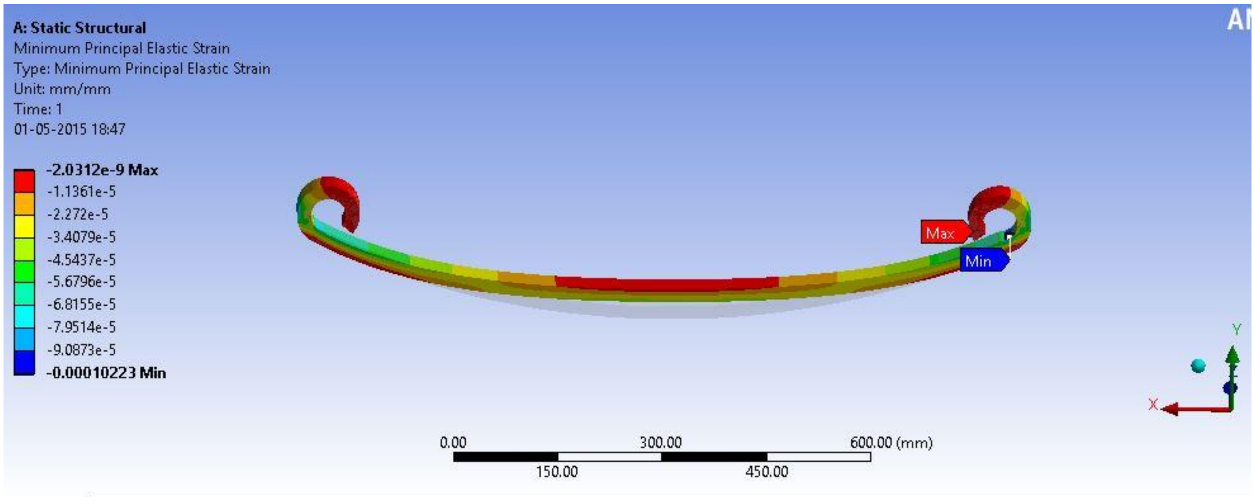

Figure 6. 21Minimum Principal Strain At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Elastic Strain being produced in the conventional steel spring and we see that maximum strain produced is -2.0312e-9 and minimum is -0.00010223.

6.6.3 Principal Stress at different loads 3300N

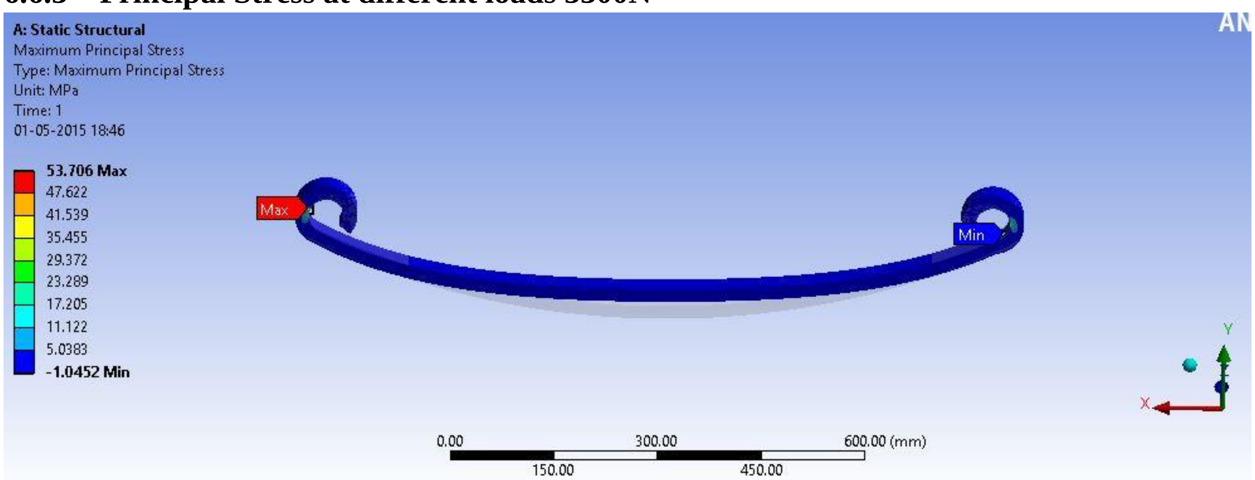

Figure 6. 22 Maximum Principal Stress At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress being produced in the conventional steel spring and we see that maximum stress produced is 53.706 MPa and minimum is-1.0452 MPa.

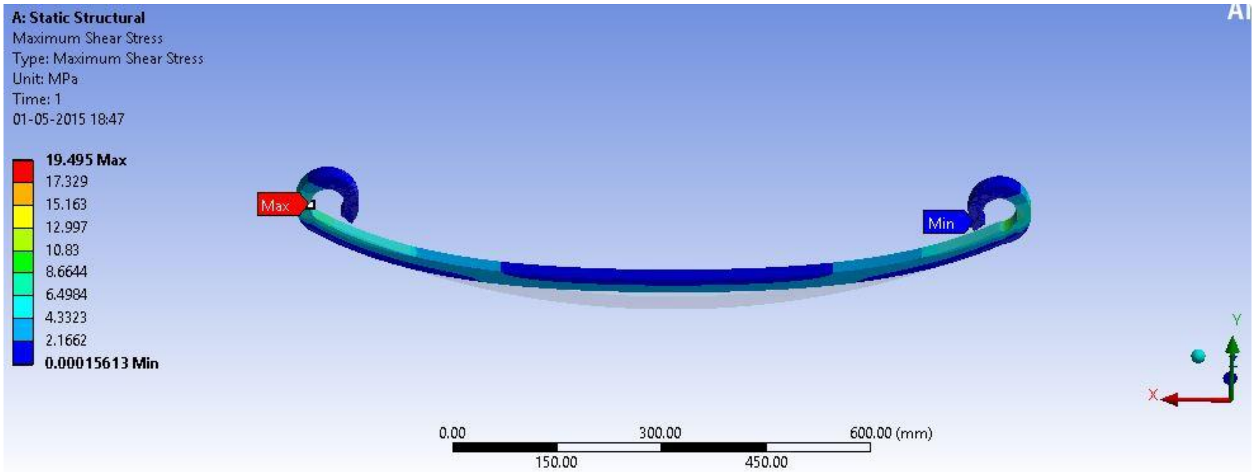

Figure 6. 23 Maximum Shear Stress At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress being produced in the conventional steel spring and we see that maximum stress produced is 19.495 MPa and minimum is 0.00015613 MPa.

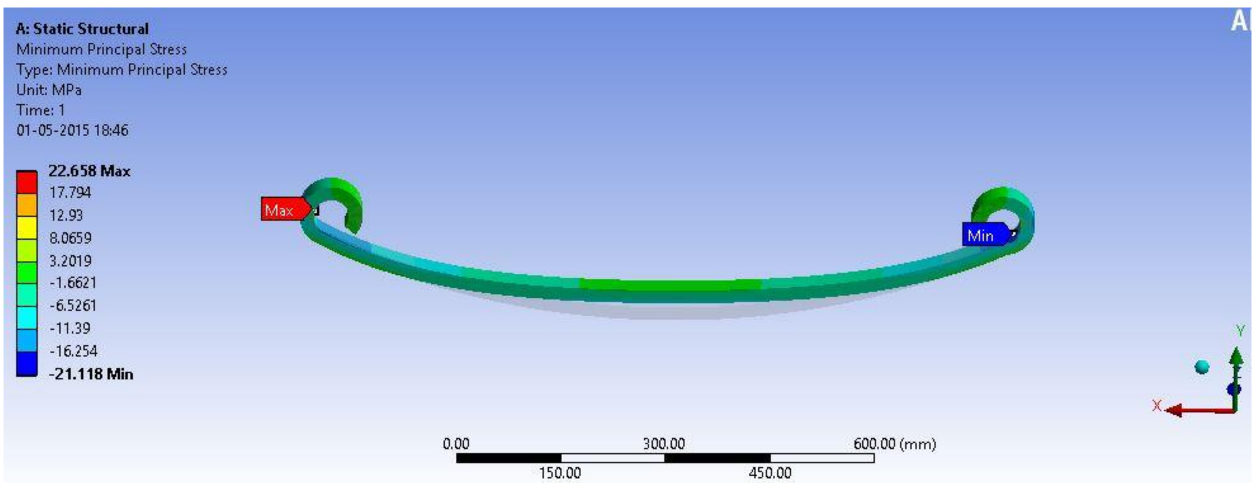

Figure 6. 24 Minimum Principal Stress At 3300N

In the above shown figure at the base surface of the steel spring a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Stress being produced in the conventional steel spring and we see that maximum stress produced is 22.658 MPa and minimum is -21.118 MPa.

6.7 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 0^0

6.7.1 Total Deformation at different Loads At 3300 N

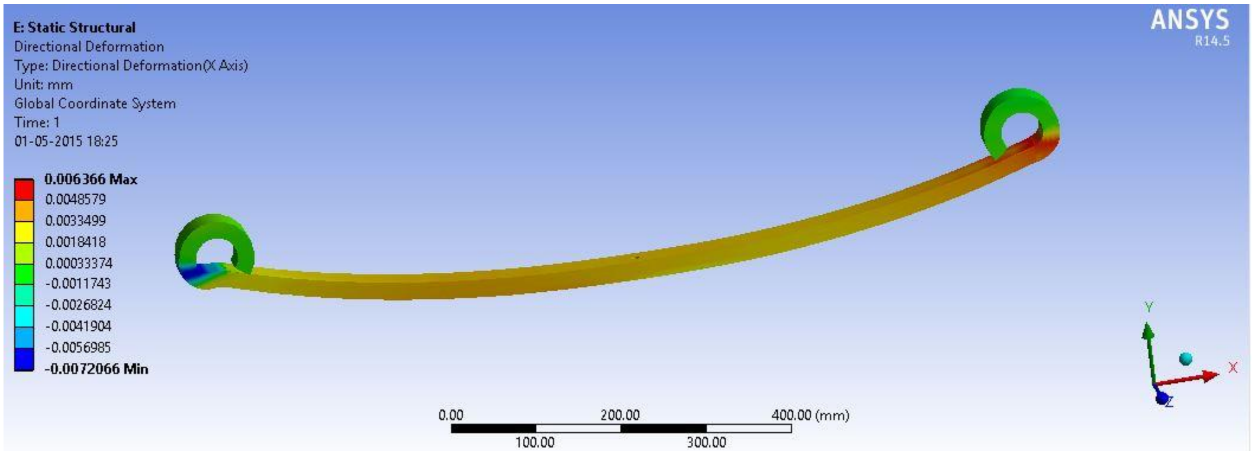

Figure 6. 25 Deformation in X Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the X direction of the composite leaf spring and we see that maximum deformation produced is 0.006366 mm and minimum is -0.0072066 mm.

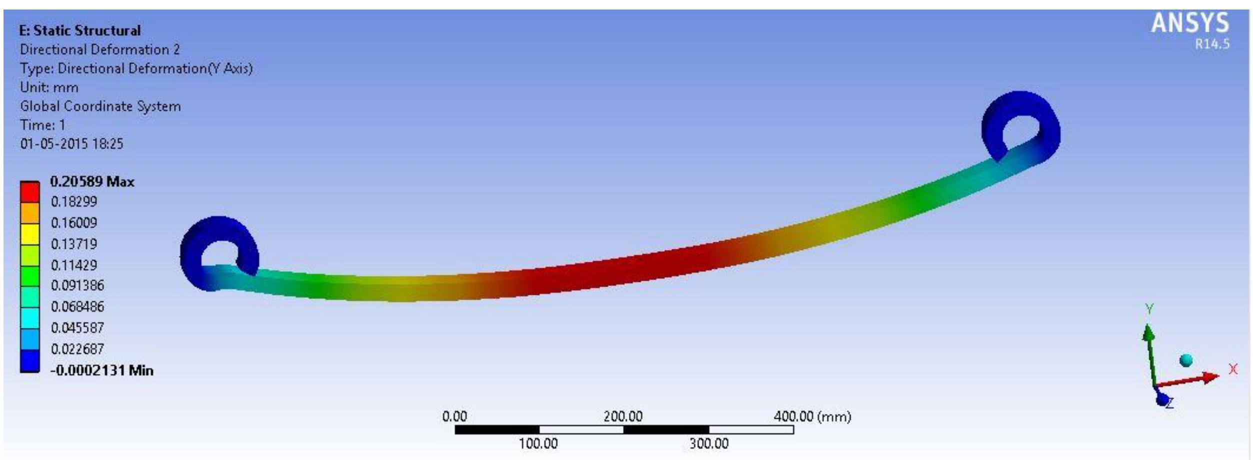

Figure 6. 26 Deformation in Y Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Y direction of the composite leaf spring and we see that maximum deformation produced is 0.020589 mm and minimum is -0.0002131mm.

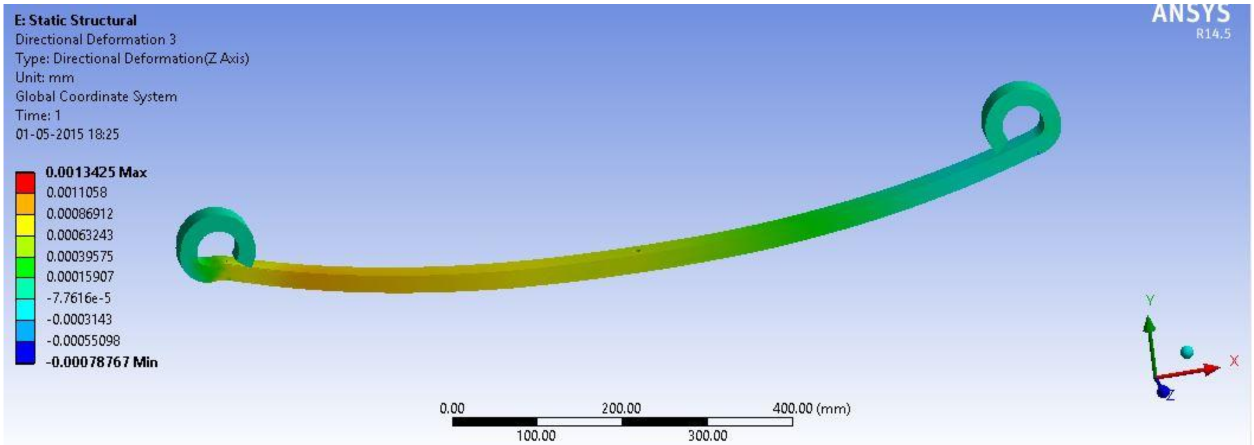

Figure 6. 27 Deformation in Z Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Z direction of the composite leaf spring and we see that maximum deformation produced is 0.0013425 mm and minimum is -0.00078767 mm.

6.7.2 Equivalent Stress at different Loads At 3300 N

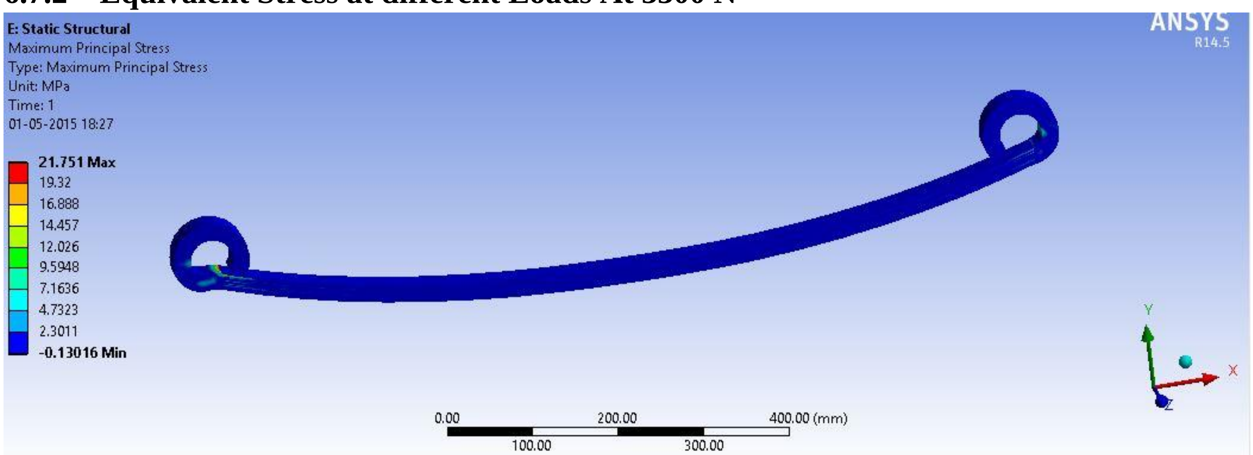

Figure 6. 28 Maximum Principal Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 21.751 MPa and minimum is -0.13016 MPa.

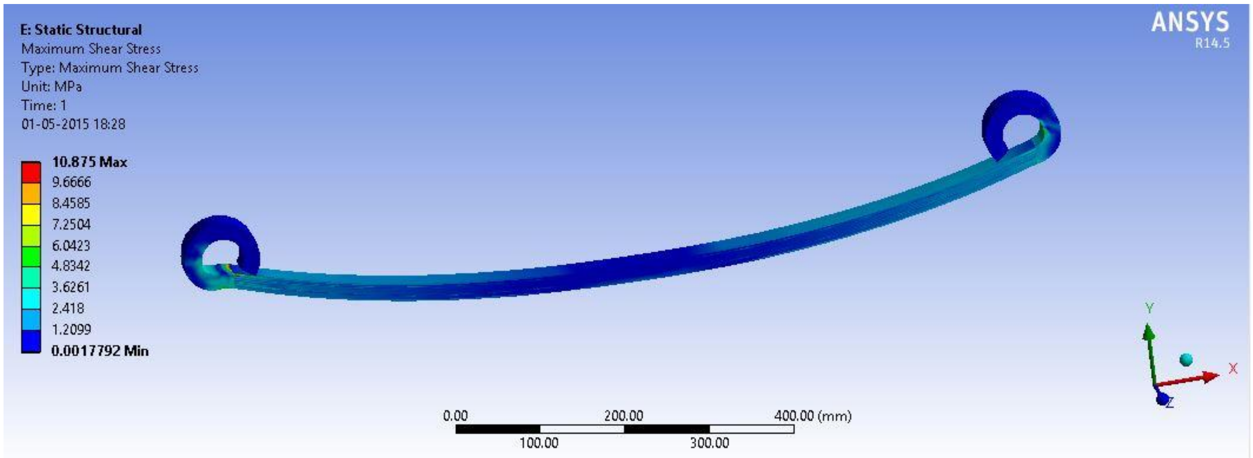

Figure 6. 29 Maximum Shear Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Stress produced in the composite leaf spring and we see that maximum stress produced is 10.875 MPa and minimum is 0.0017792 MPa.

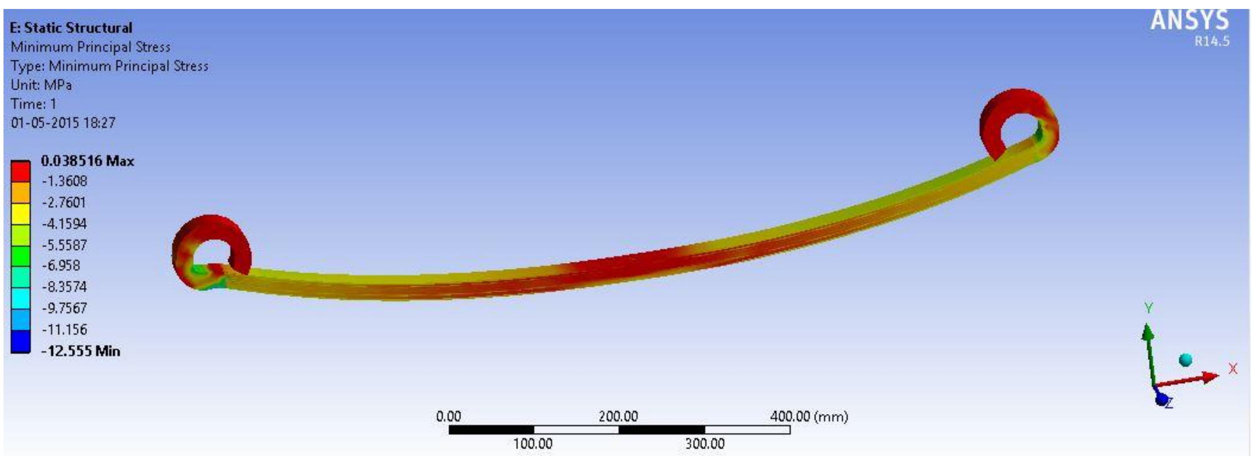

Figure 6. 30 Maximum Principal Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 0.038516 MPa and minimum is -12.555 MPa.

6.7.3 Equivalent Strains at different loads 3300N

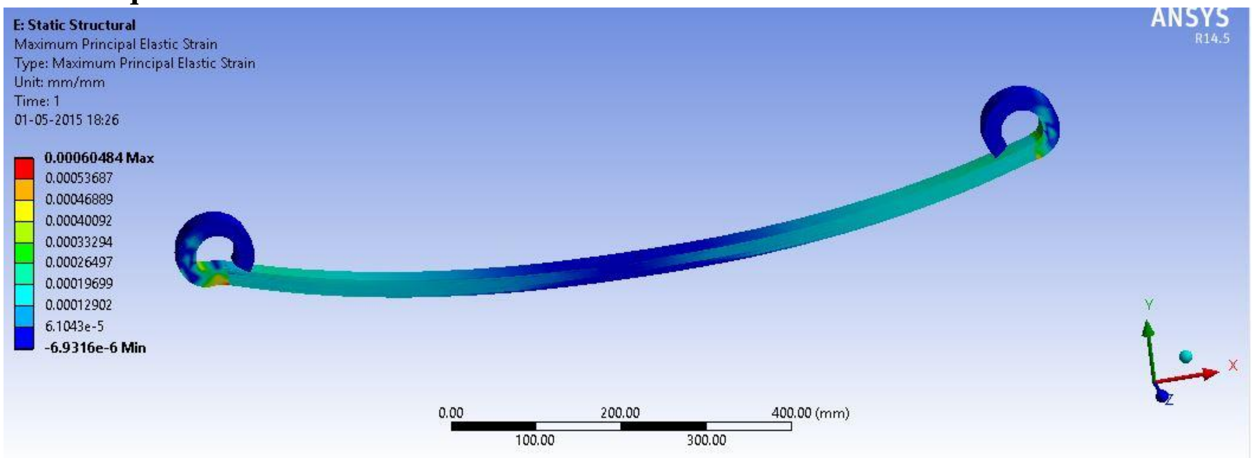

Figure 6. 31 Maximum Principal Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Strain produced in the composite leaf spring and we see that maximum strain produced is 0.00060484 and minimum is -6.9316e-6.

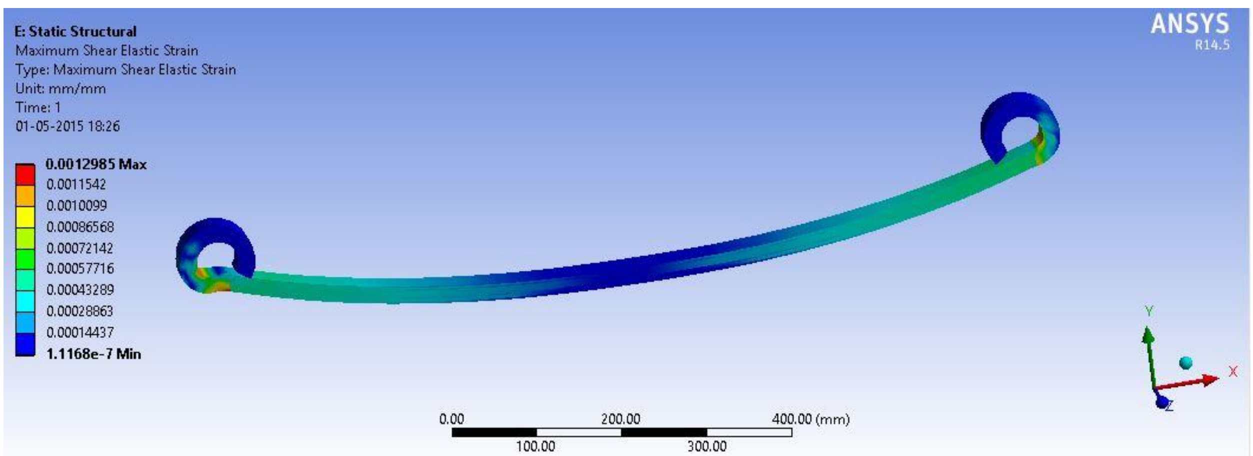

Figure 6. 32 Maximum Shear Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Strain produced in the composite leaf spring and we see that maximum strain produced is 0.0012985 and minimum is 1.1168e-7.

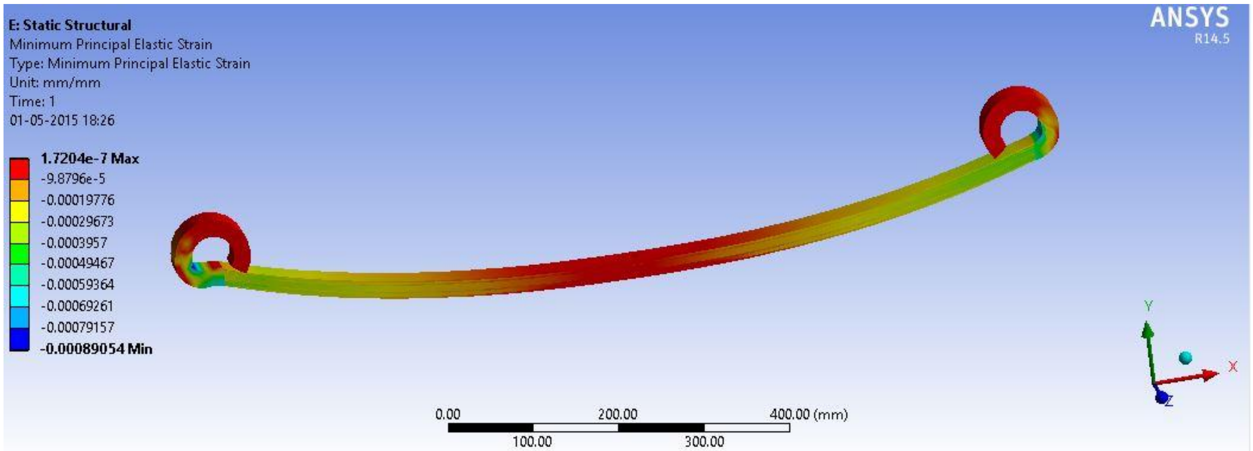

Figure 6. 33 *Minimum Principal Strain At 3300N*

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 0^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Strain produced in the composite leaf spring and we see that maximum strain produced is 1.7204e-7 and minimum is -0.0008905.

6.8 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 30^0

6.8.1 Deformation at various loads At 3300N

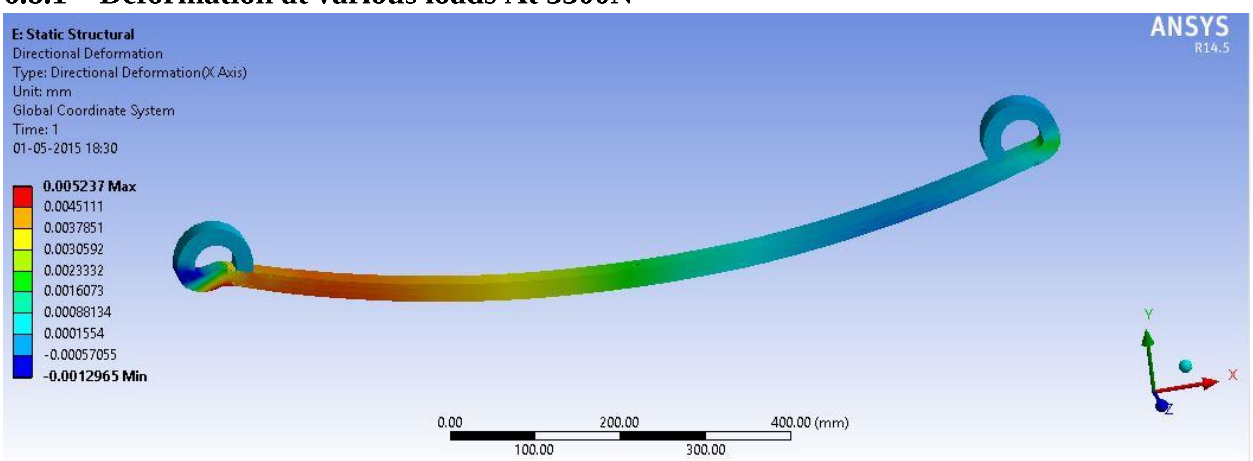

Figure 6. 34 Deformation in X Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the X direction of the composite leaf spring and we see that maximum deformation produced is 0.005237 mm and minimum is -0.0012965 mm.

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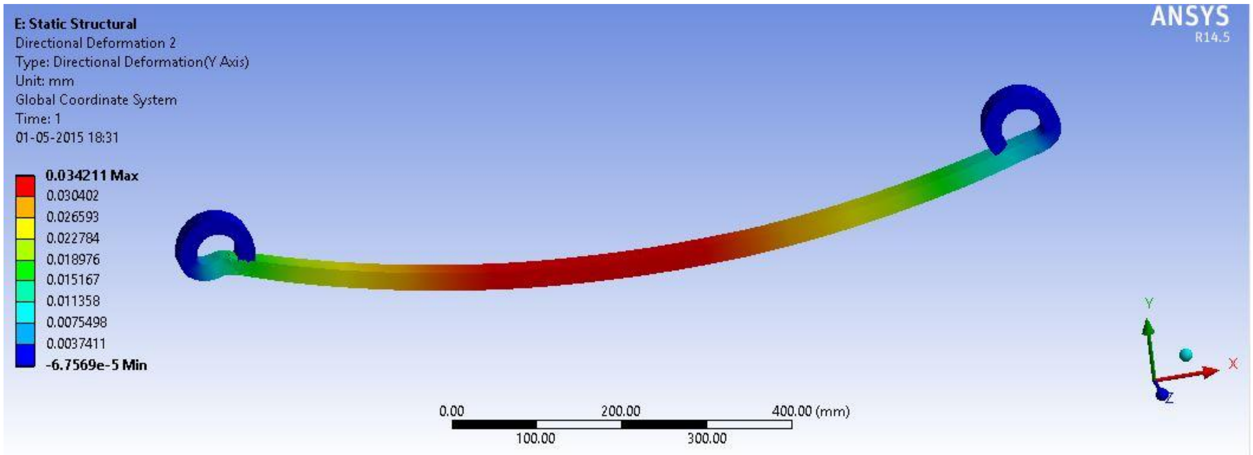


Figure 6. 35 Deformation in Y Axis At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Y direction of the composite leaf spring and we see that maximum deformation produced is 0.034211 m and minimum is -6.7569e-5 m.

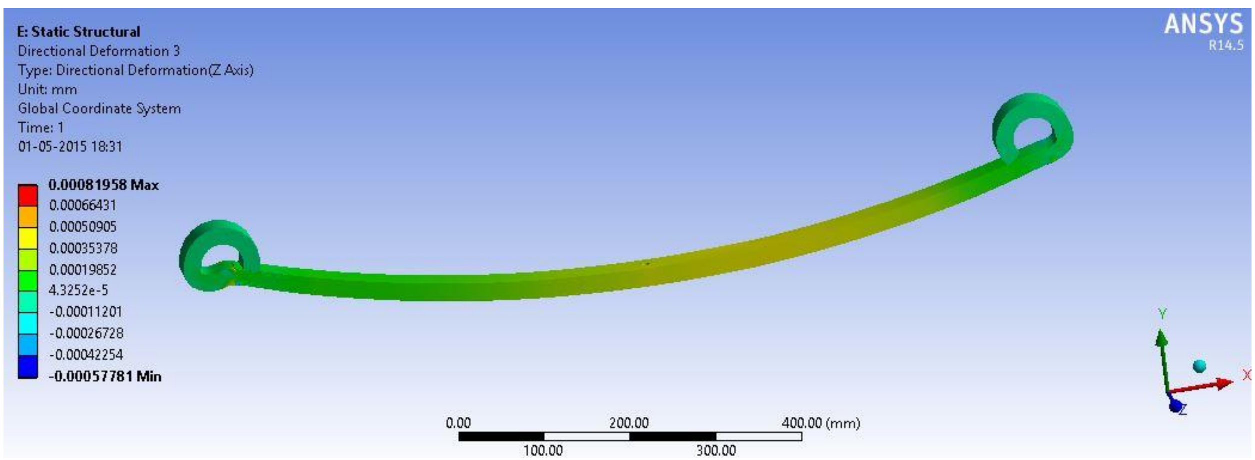


Figure 6. 36 Deformation in Z Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Z direction of the composite leaf spring and we see that maximum deformation produced is 0.00081958 m and minimum is -0.00057781 m.

6.8.2 Principal Strain at various loads At 3300N

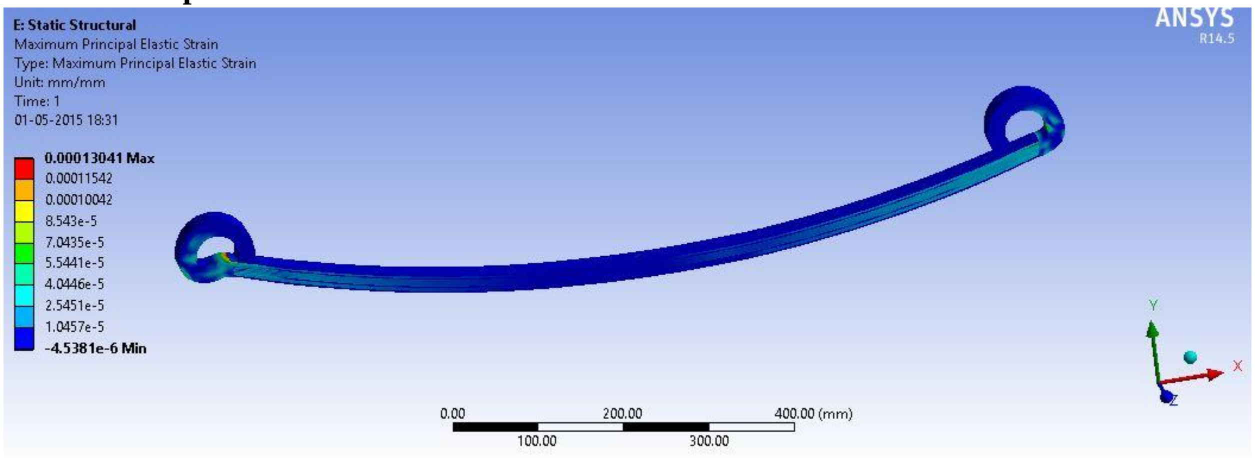


Figure 6. 37 Maximum Principal Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Strain produced in the composite leaf spring and we see that maximum stress produced is 0.00013041 and minimum is -4.5381e-6.

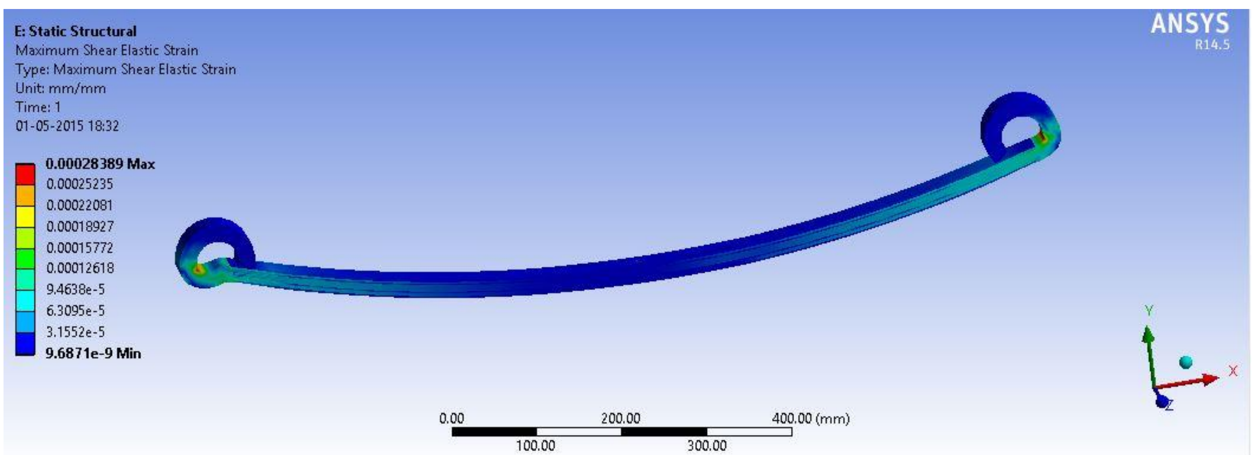


Figure 6. 38 Maximum Shear Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Strain produced in the composite leaf spring and we see that maximum stress produced is 0.00028389 and minimum is 9.6871e-9.

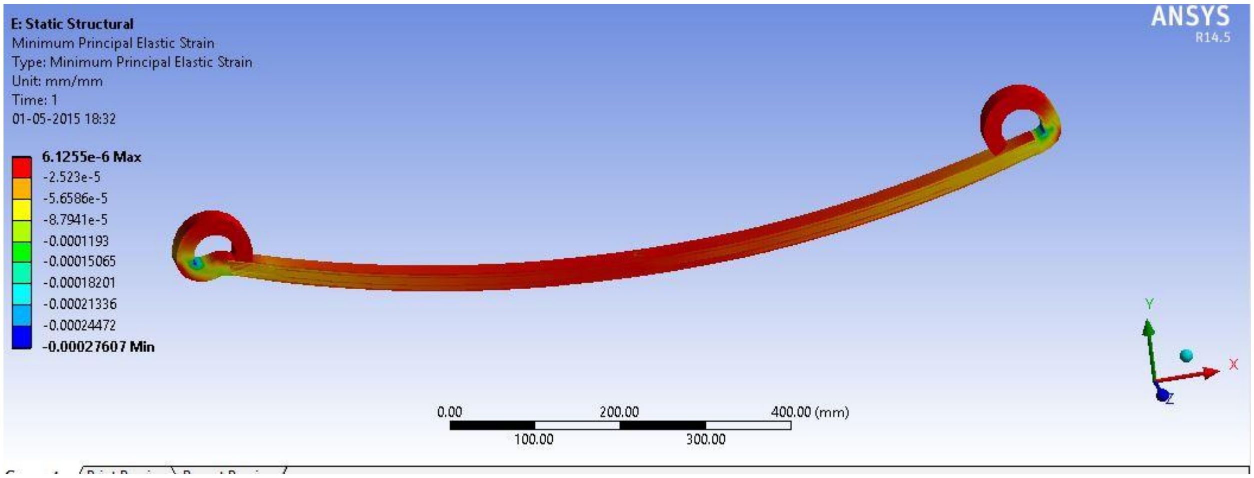


Figure 6. 39 Minimum Principal Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 6.1255e-6 and minimum is -0.00027607.

6.8.3 Principal Stress at various loads At 3300N

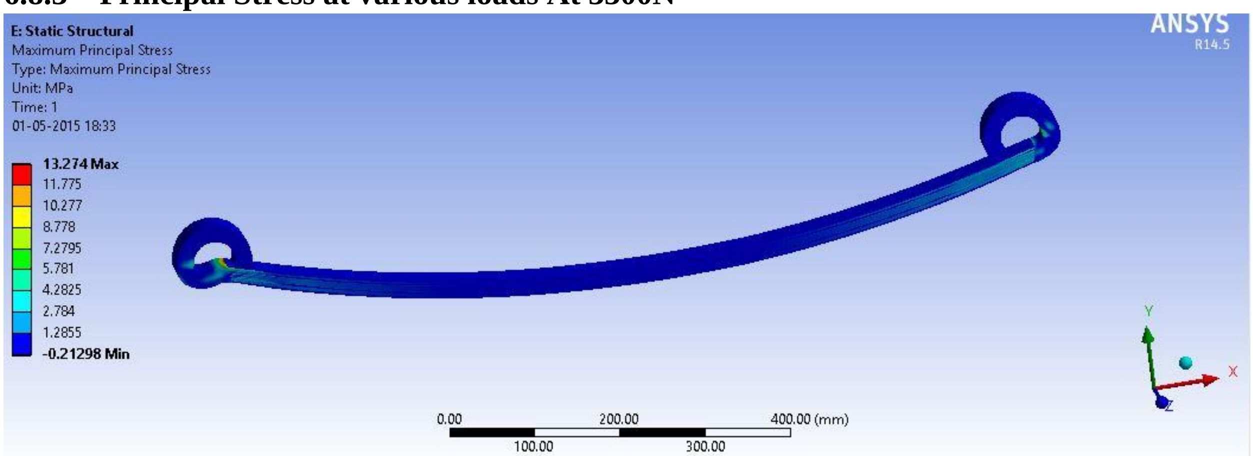


Figure 6. 40 Maximum Principal Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 13.274 MPa and minimum is -0.21298 MPa.

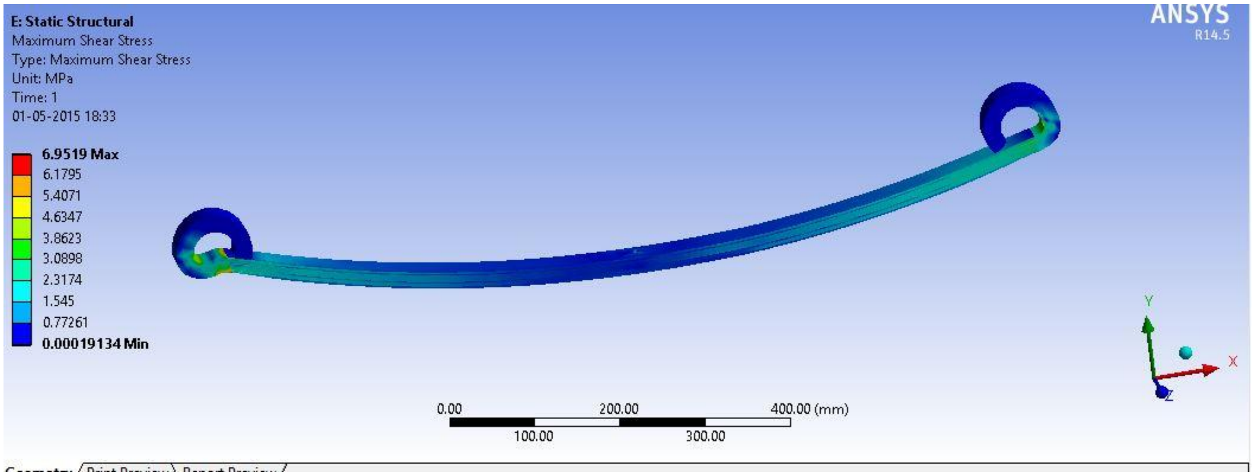


Figure 6. 41 Maximum Shear Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Stress produced in the composite leaf spring and we see that maximum stress produced is 6.9519 MPa and minimum is 0.00019134MPa.

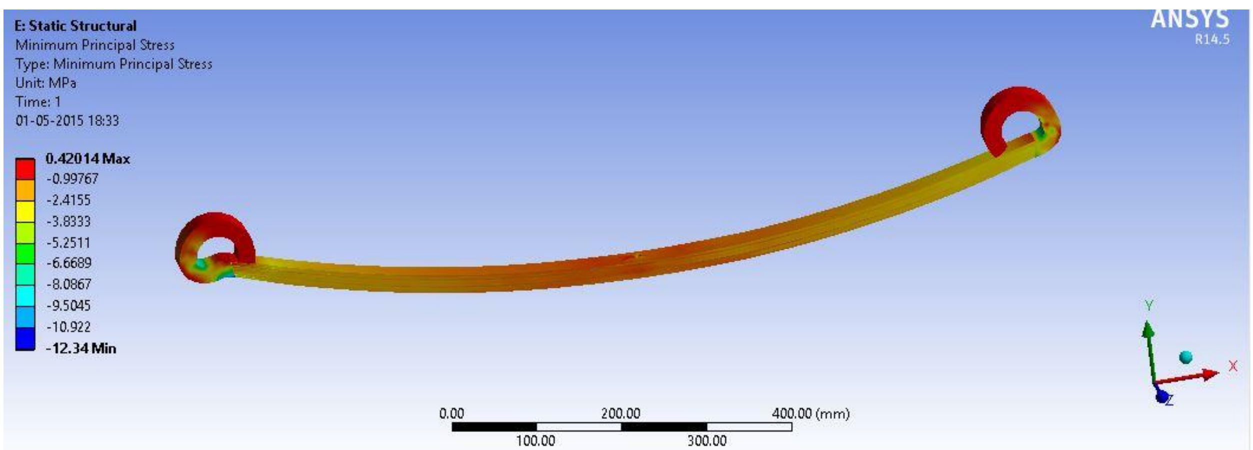


Figure 6. 42 Minimum Principal Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 30^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 0.42014 MPa and minimum is -12.34 MPa.

6.9 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 45^0

6.9.1 Total Deformation at different Loads At 3300 N

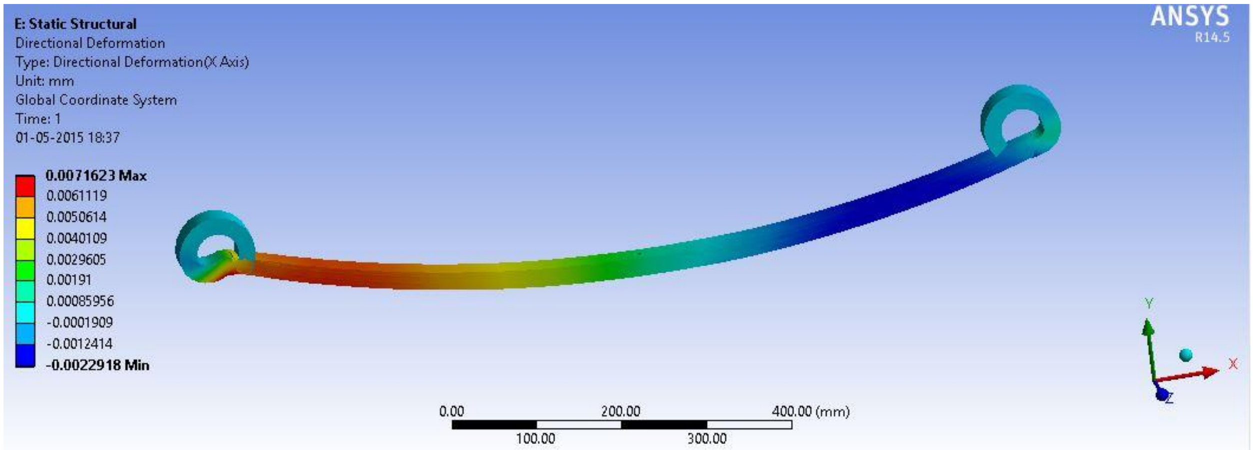


Figure 6. 43 Deformation in X Axis At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the X direction of the composite leaf spring and we see that maximum deformation produced is 0.0071623 m and minimum is -0.0022918 m.

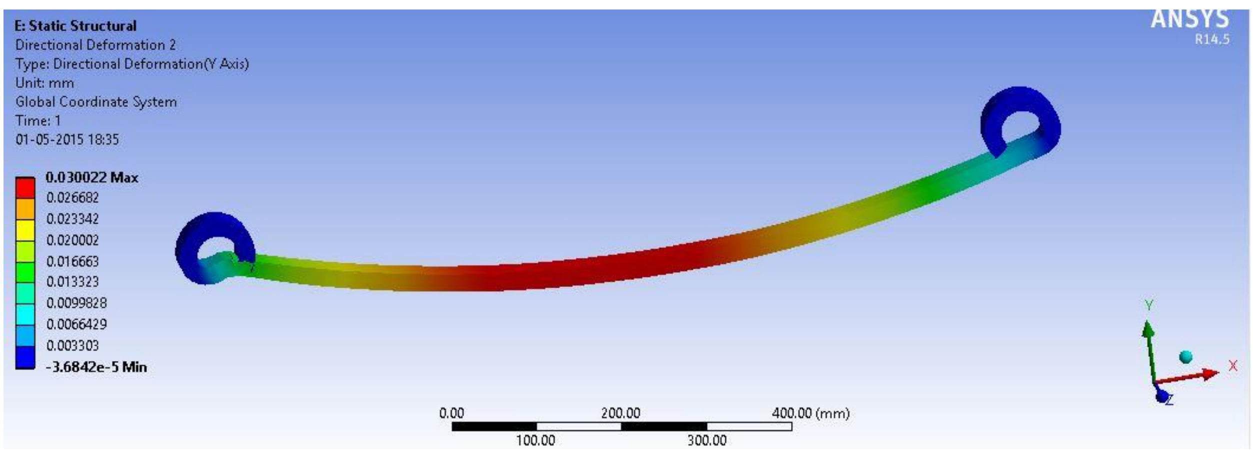


Figure 6. 44 Deformation in Y Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Y direction of the composite leaf spring and we see that maximum deformation produced is 0.030022 m and minimum is -3.6842e-5 m.

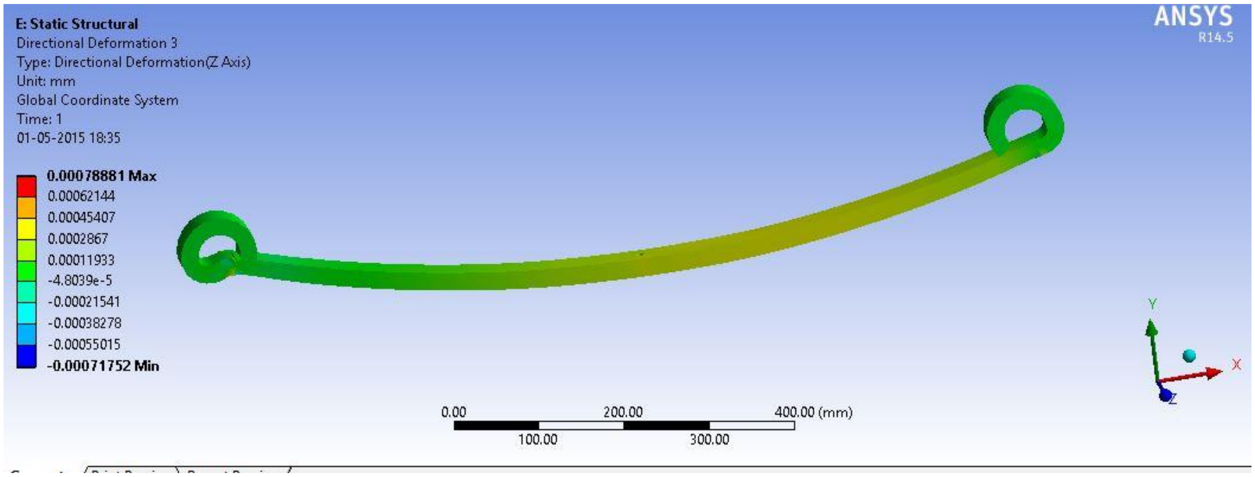


Figure 6. 45 Deformation in Z Axis At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Z direction of the composite leaf spring and we see that maximum deformation produced is 0.00078881 m and minimum is -0.00071752 m.

6.9.2 Equivalent Strain at different loads 3300N

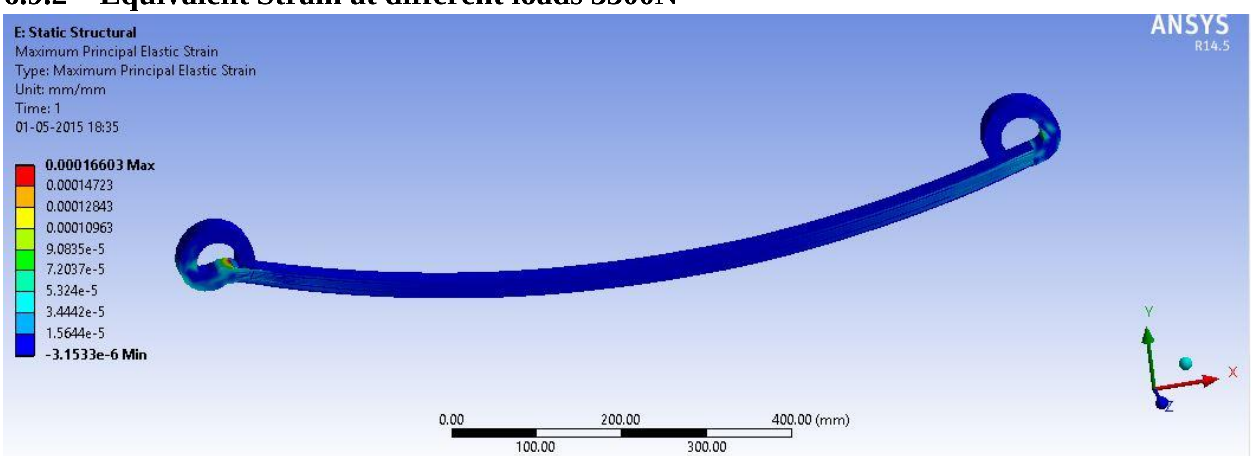


Figure 6. 46 Maximum Principal Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Strain produced in the composite leaf spring and we see that maximum strain produced is 0.00016603 and minimum is -3.1533e-6.

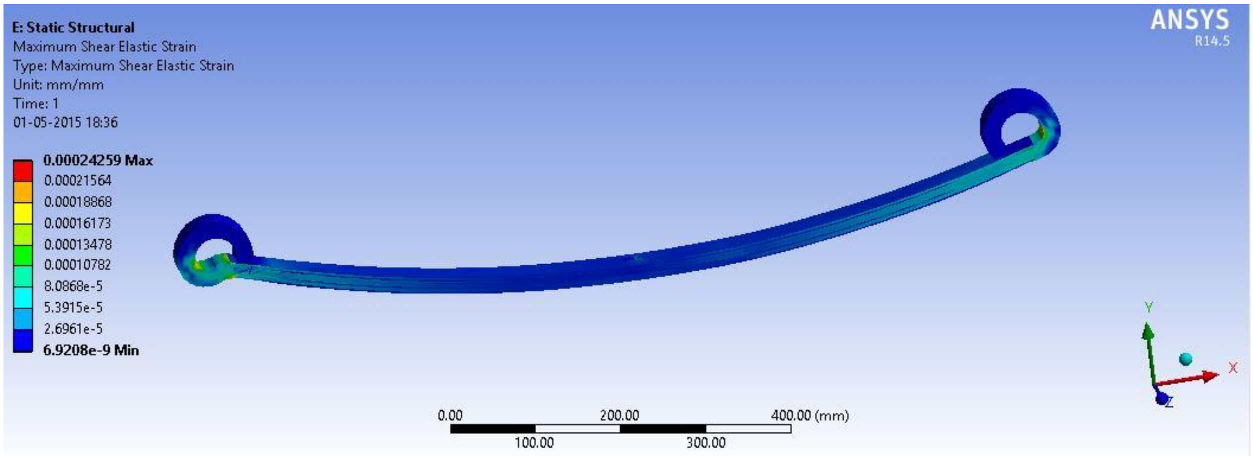


Figure 6. 47 Maximum Shear Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Strain produced in the composite leaf spring and we see that maximum strain produced is 0.00024259 and minimum is 6.9208e-9.

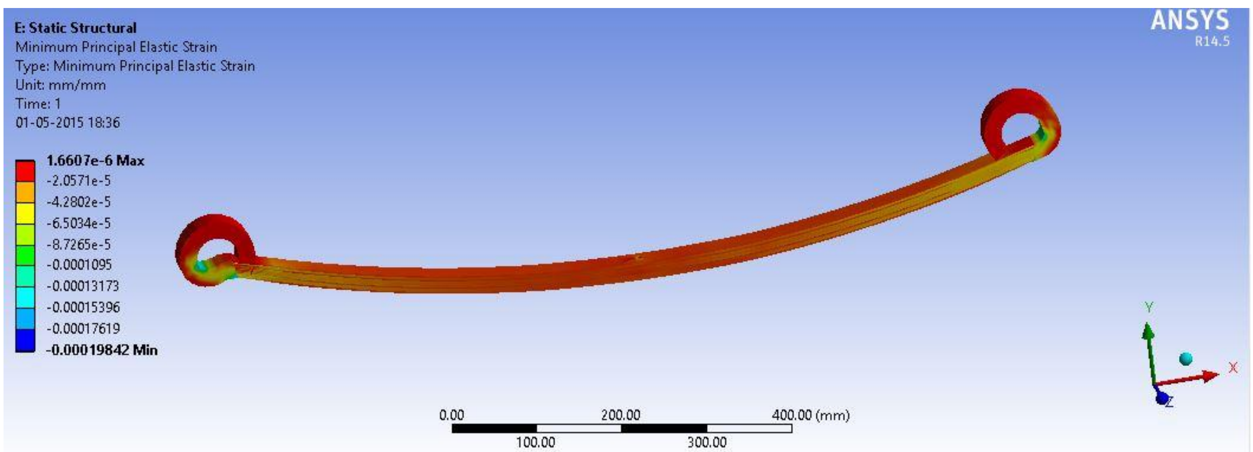


Figure 6. 48 Minimum Principal Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Strain produced in the composite leaf spring and we see that maximum strain produced is 1.6607e-6 and minimum is -0.00019842.

6.9.3 Equivalent Stress at different loads 3300N

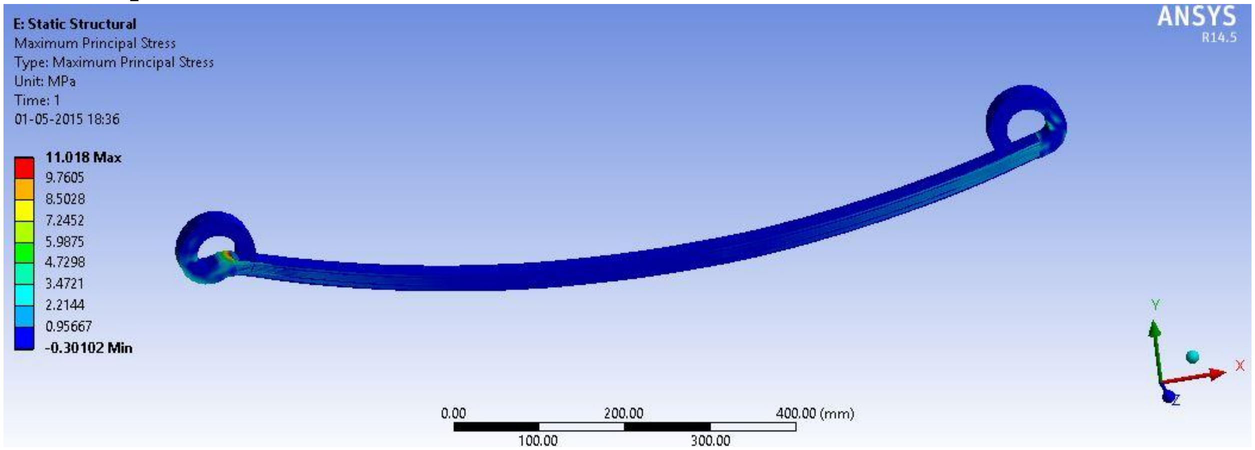


Figure 6. 49 Maximum Principal Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 11.018 MPa and minimum is -0.30102MPa.

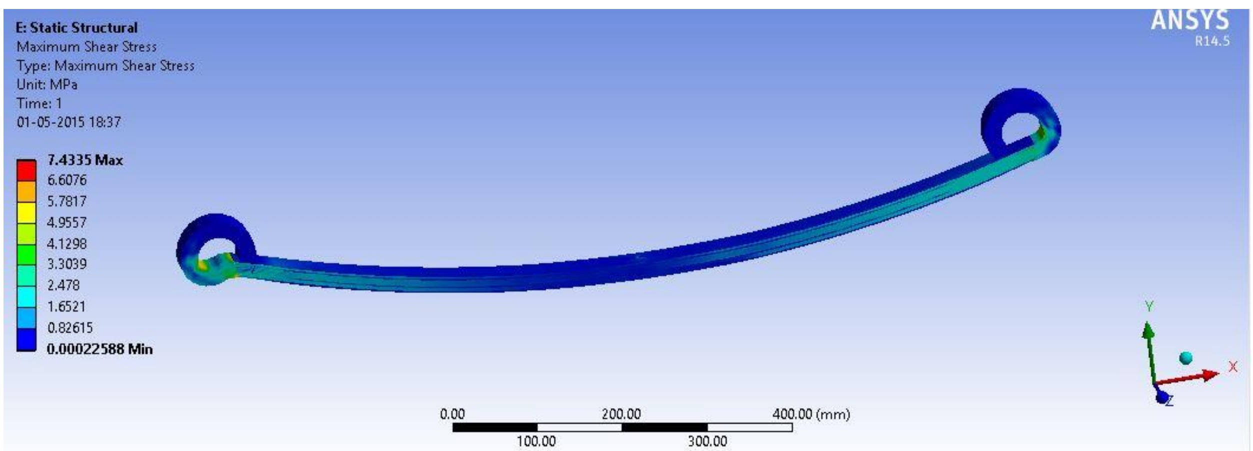


Figure 6. 50 Maximum Shear Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Stress produced in the composite leaf spring and we see that maximum stress produced is 7.4335 MPa and minimum is 0.00022588 MPa.

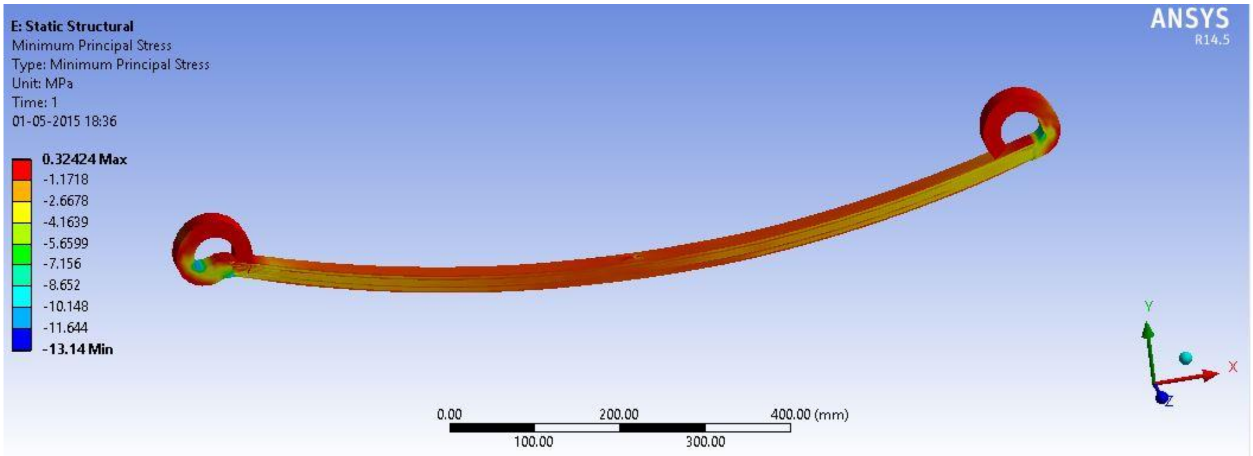


Figure 6. 51 Minimum Principal Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 0.32424 MPa and minimum is -13.14MPa.

6.10 When Tested over Composite Leaf Spring made of Carbon-Epoxy at 90^0

6.10.1 Total Deformation at different Loads At 3300 N

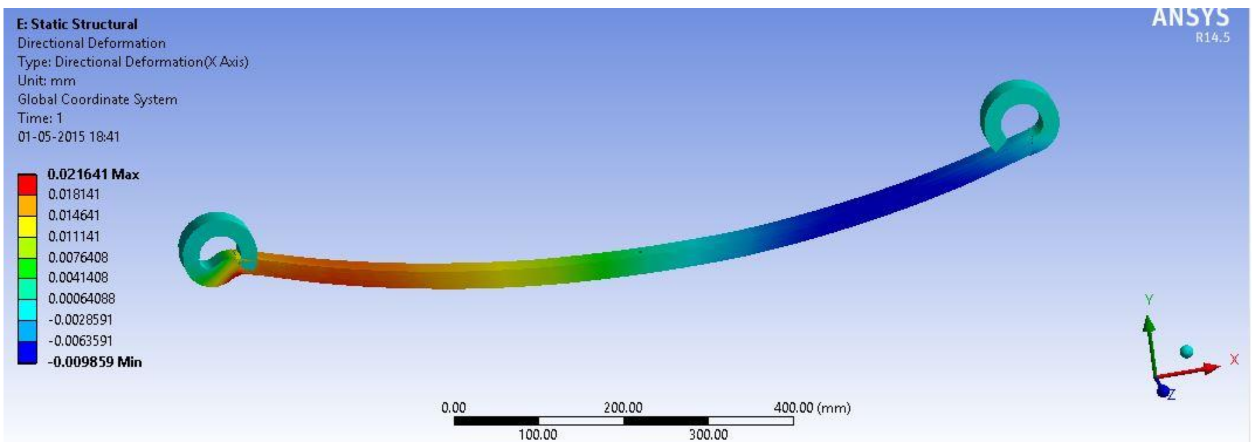


Figure 6. 52 Deformation in X Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the X direction of the composite leaf spring and we see that maximum deformation produced is 0.021641 mm and minimum is -0.009859 mm.

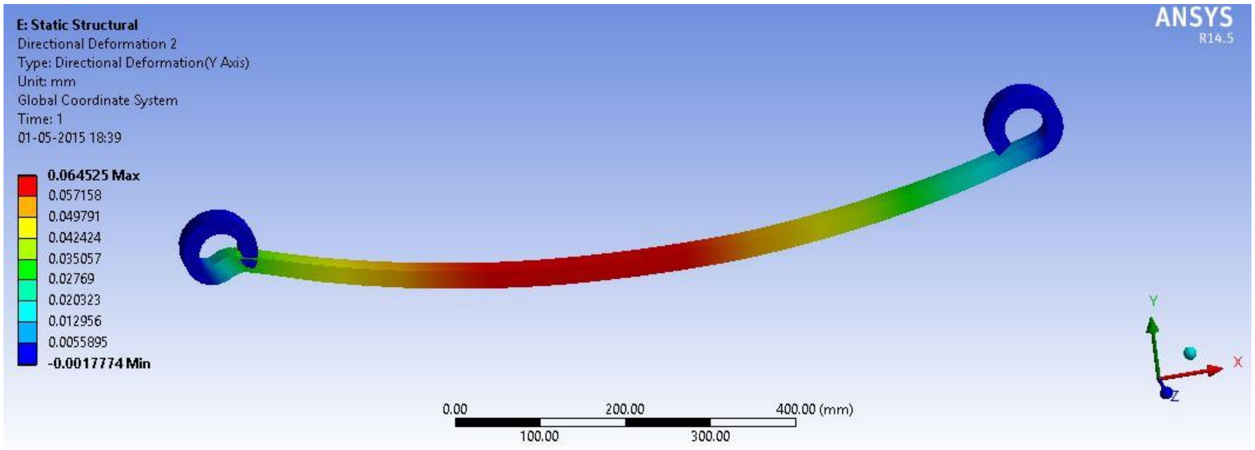


Figure 6. 53 Deformation in Y Axis at 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Y direction of the composite leaf spring and we see that maximum deformation produced is 0.064525 mm and minimum is -0.0017774 mm.

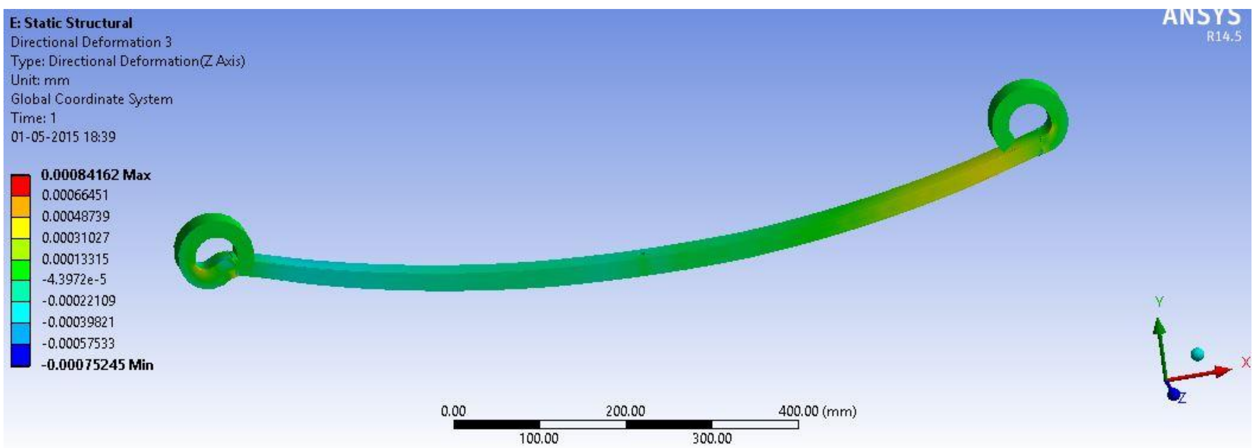


Figure 6. 54 Deformation in Z Axis At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the deformation produced in the Z direction of the composite leaf spring and we see that maximum deformation produced is 0.00084162 mm and minimum is -0.00075245 mm.

6.10.2 Equivalent Strain at different loads 3300N

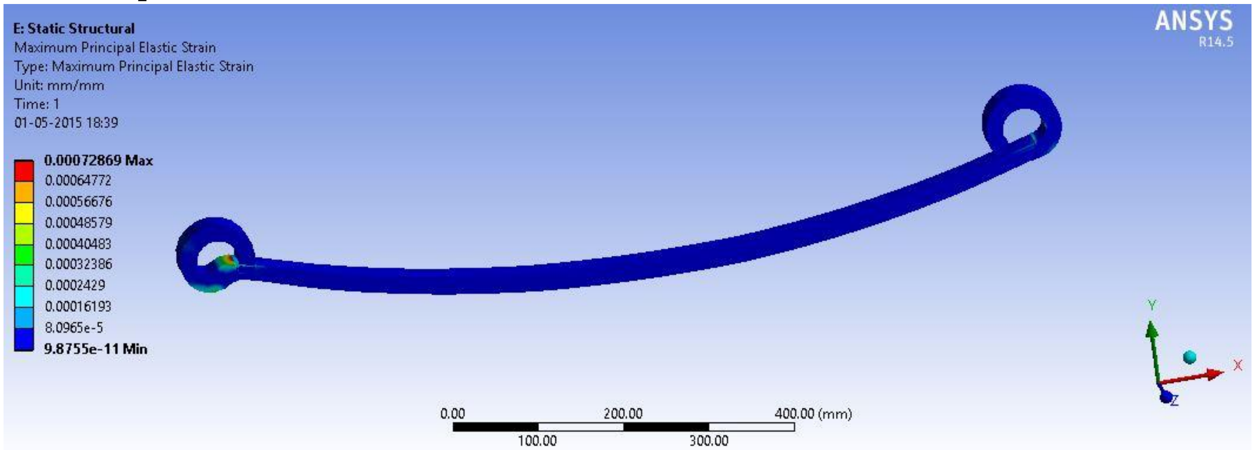


Figure 6. 55 Maximum Principal Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Strain produced in the composite leaf spring and we see that maximum strain produced is 0.00072869 and minimum is 9.8755e-11.

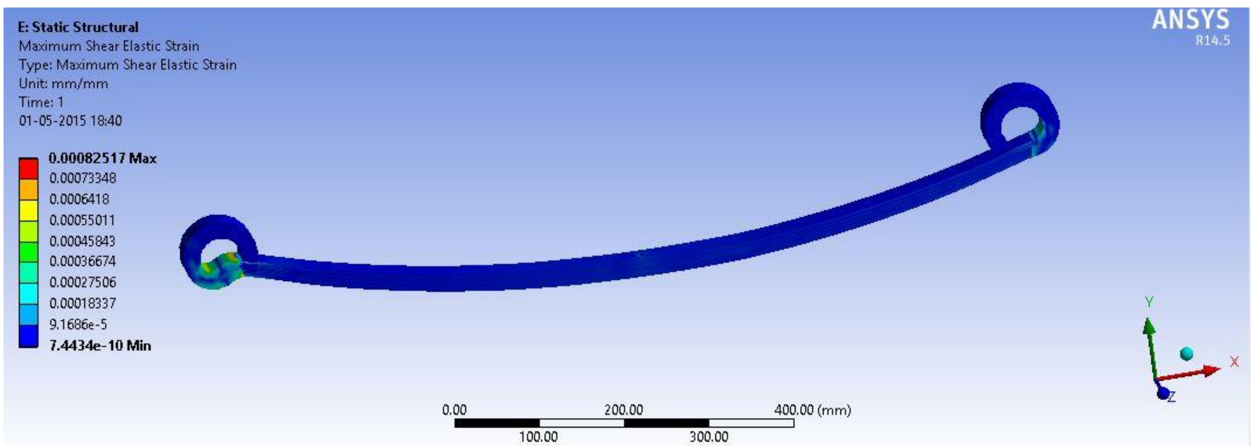


Figure 6. 56 Maximum Shear Strain At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 45^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Shear Strain produced in the composite leaf spring and we see that maximum strain produced is 0.00082517 and minimum is 7.4434e-10.

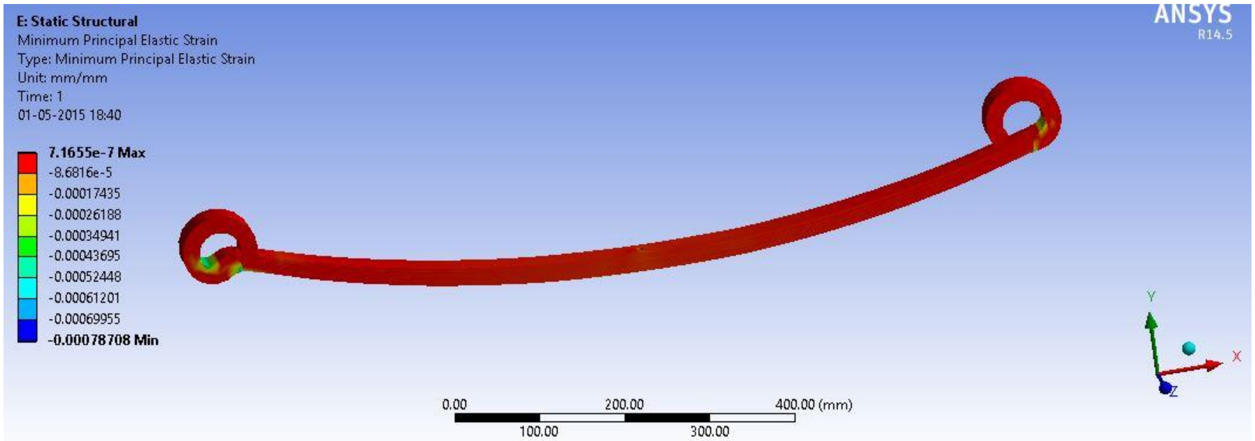


Figure 6. 57 *Minimum Principal Strain At 3300N*

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Strain produced in the composite leaf spring and we see that maximum strain produced is 7.1655e-7 and minimum is -0.00078708.

6.10.3 Equivalent Stress at different loads 3300N

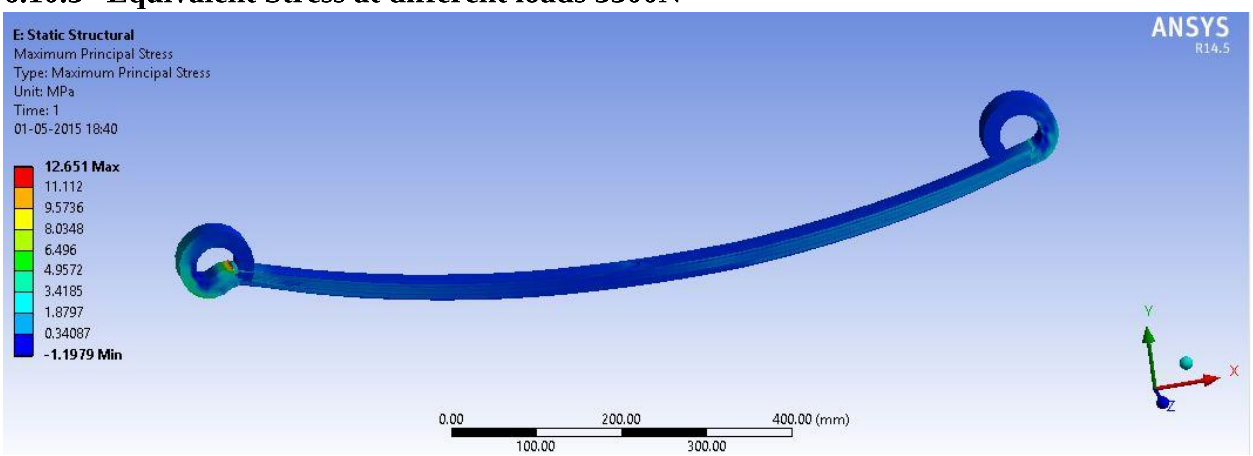


Figure 6. 58 Maximum Principal Stress At 3300N

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 12.651 MPa and minimum is -1.1979 MPa.

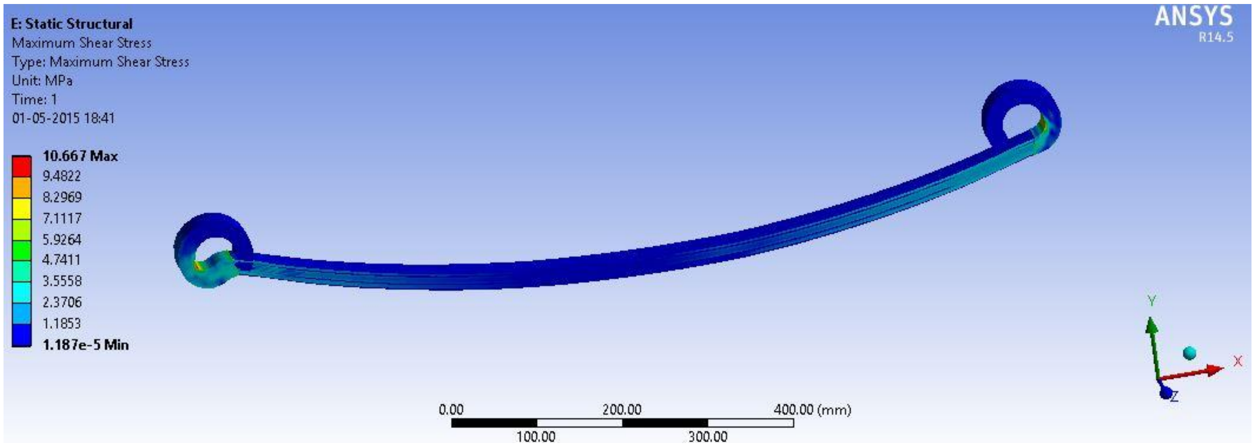


Figure 6. 59 *Maximum Shear Stress At 3300N*

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 10.667 MPa and minimum is 1.187e-5 MPa.

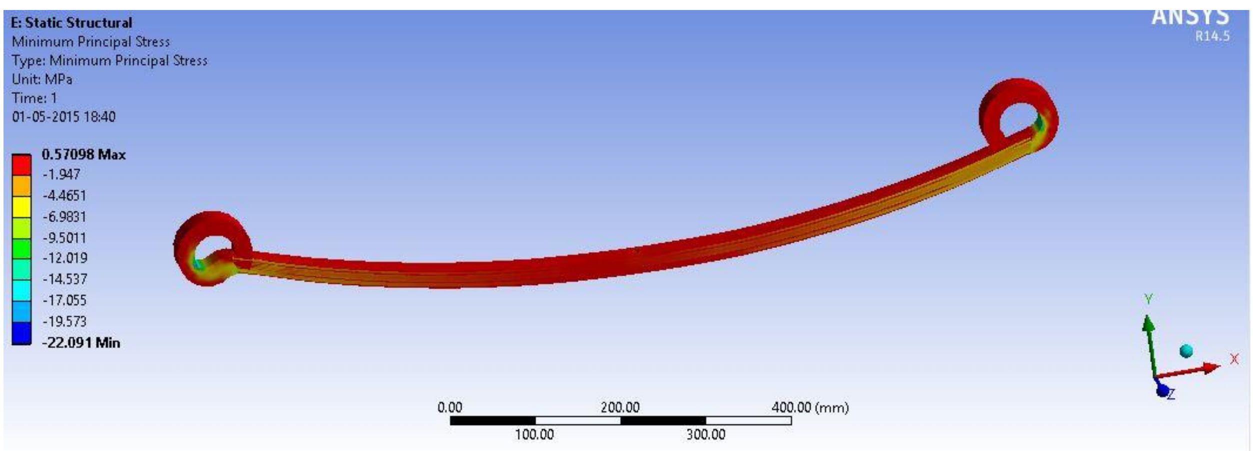
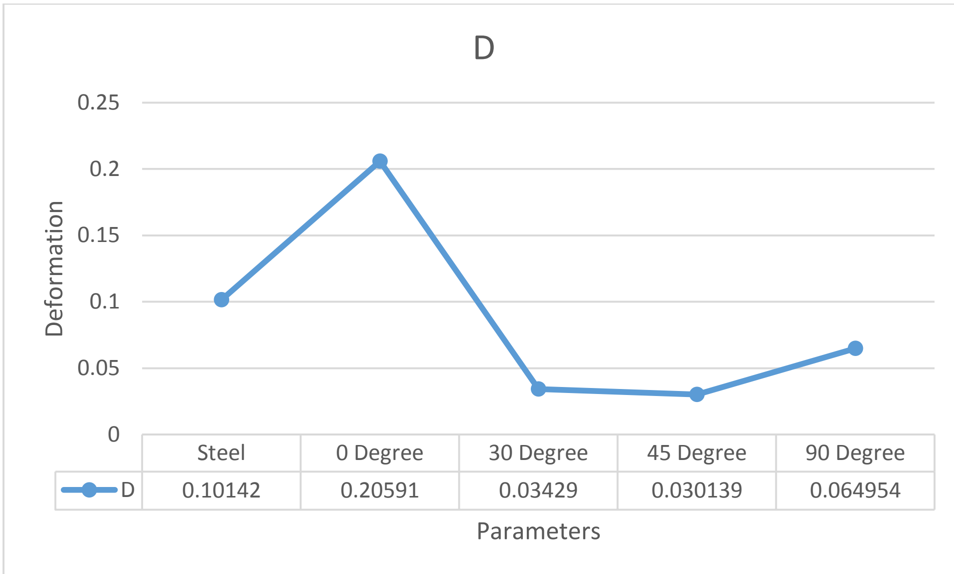


Figure 6. 60 *Minimum Principal Stress At 3300N*

In the above shown figure at the base surface of the composite material spring made of carbon-epoxy at an angle of 90^0 a force of 3300N is being applied while keeping both the eyes ends as fixed and we determine the Principal Stress produced in the composite leaf spring and we see that maximum stress produced is 0.57098 MPa and minimum is -22.091 MPa.

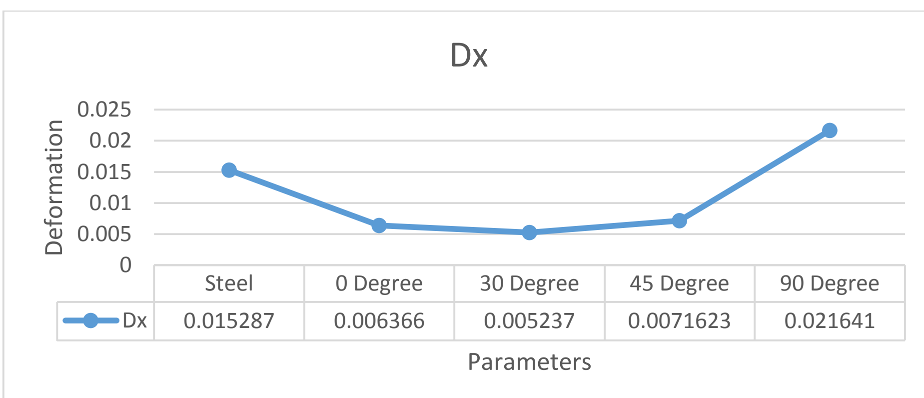
Chapter 7

7 Conclusion



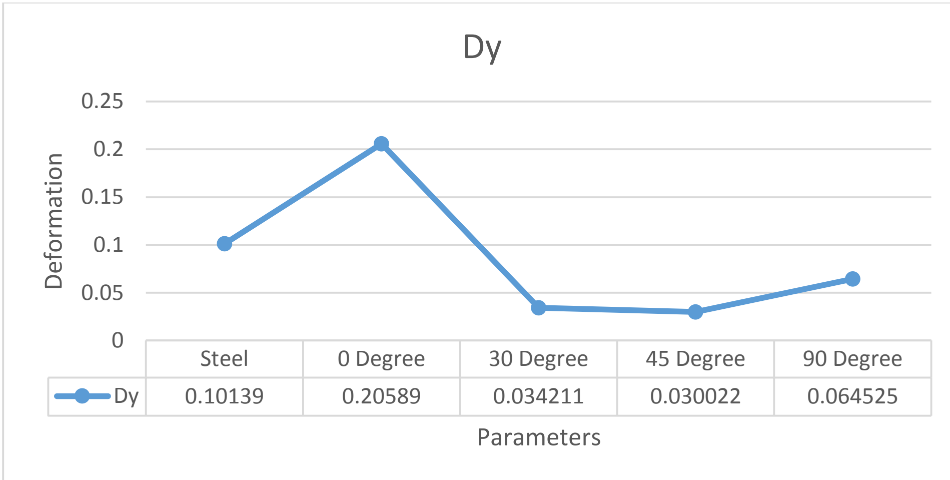
Graph 7. 1 Total Deformation Produced

From the above given data we can clearly see that when the composite material when used in the fiber orientation of (30,45,90) it results into better deformation as compared to the steel material. At 30 degree 66% less deformation is produced. At 45 degree 69 % less deformation is produced.



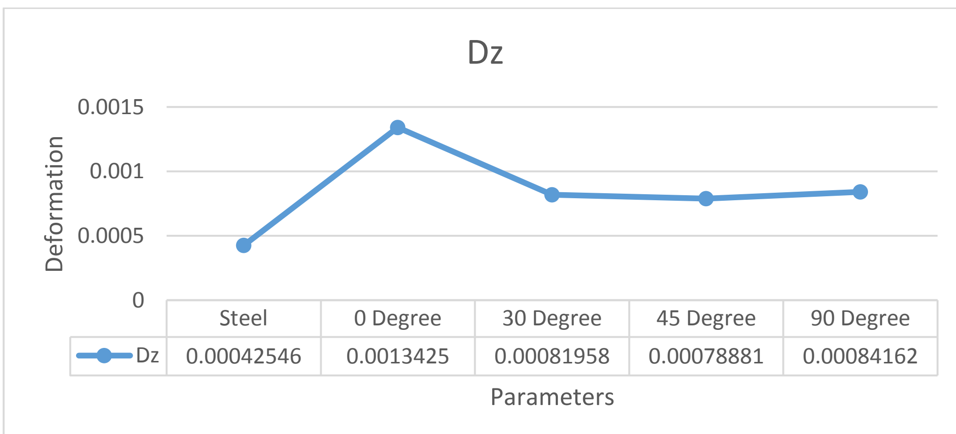
Graph 7. 2 Deformation produced in X- Axis

The deformation produced in the leaf spring in the X direction when fibers are placed at 0 degree 58.35% less deformation is found as compared to steel. At 30 degree 65.74% less deformation in X direction was noticed.



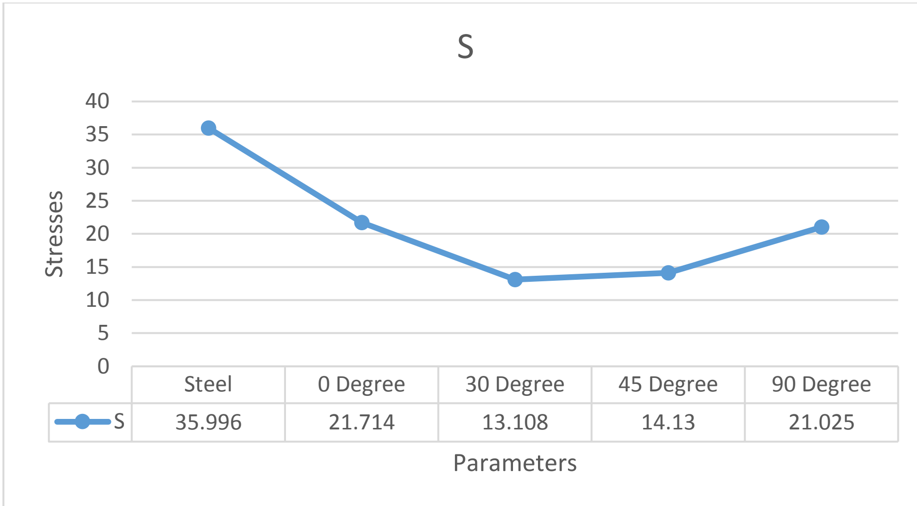
Graph 7. 3 Deformation in Y Direction

The deformation produced in y direction at 30 degree, 45 degree was noticed 66.25% and 70.38% respectively less than the deformation produced in the steel spring.



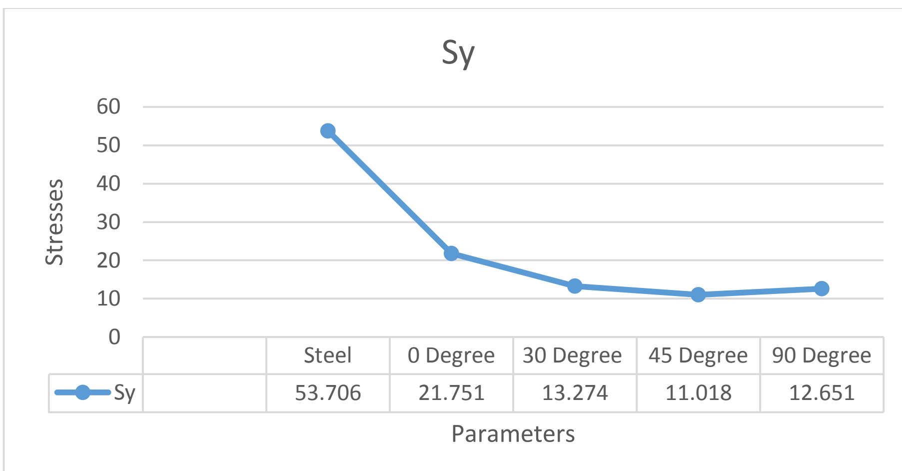
Graph 7. 4 Deformation in Z Direction

The deformation in the Z direction was better for steel as compared to the composite material's orientation at 0,30,45,90 Degree.



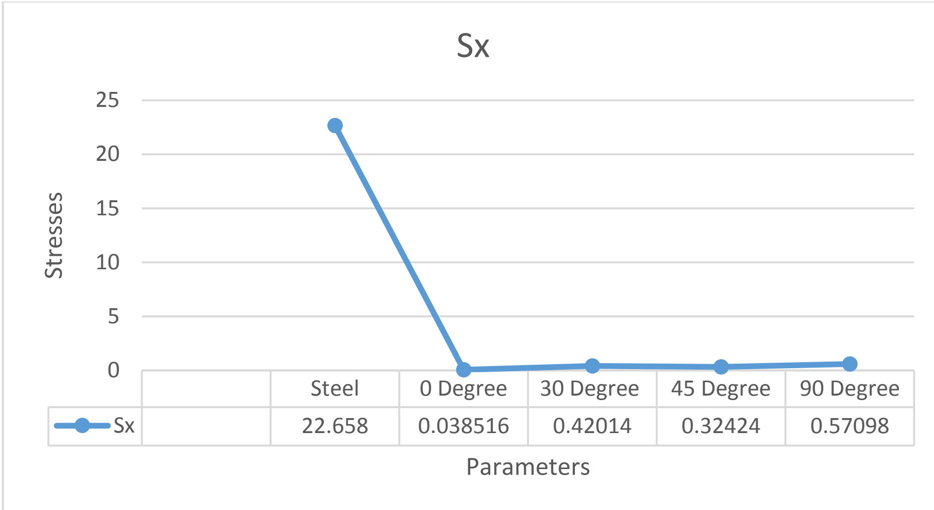
Graph 7. 5 Equivalent Stress Produced

We can clearly see that the equivalent stresses produced in the leaf spring are very less as compared to the stresses produced when fibers are placed at 0,30,45,90 degree respectively. 63.5% better at 30 degree and 60% at 45 Degree.



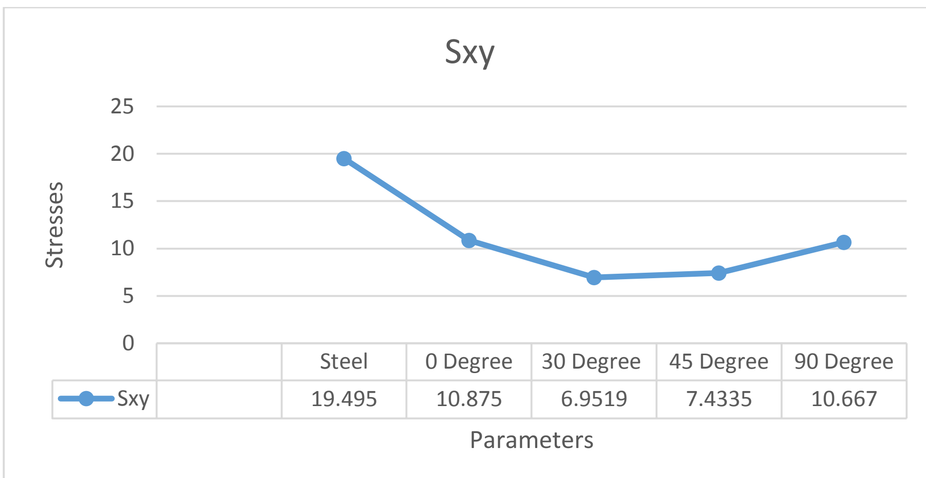
Graph 7. 6 Maximum Stress Produced

We clearly see that composite material is much better than steel at various orientations. Like 60% better at 0 Degree,75% at 30 Degree,80% at 45 Degree and 76% at 90 Degree when an comparison is being done with respect to steel.



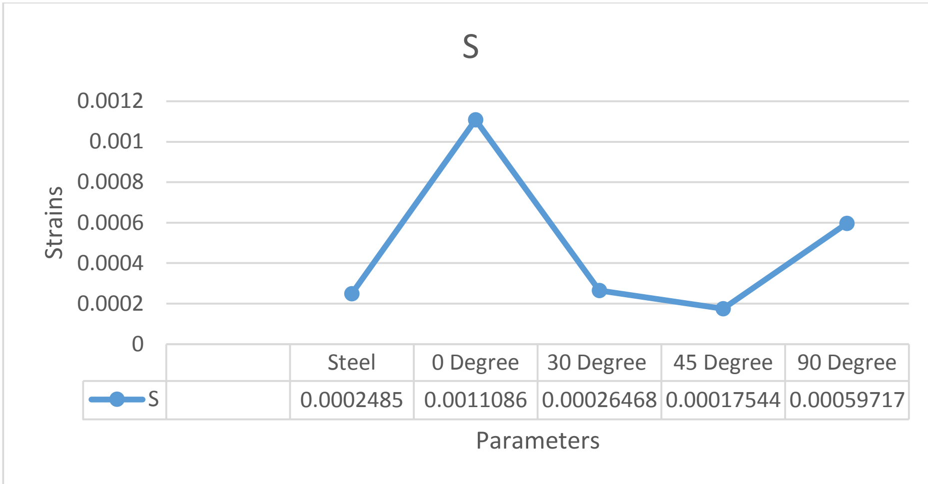
Graph 7. 7 Minimum Stress Produced

When analysis for minimum stress was done it was seen that around 99% less stresses were produced in the composite leaf spring rather than in steel.



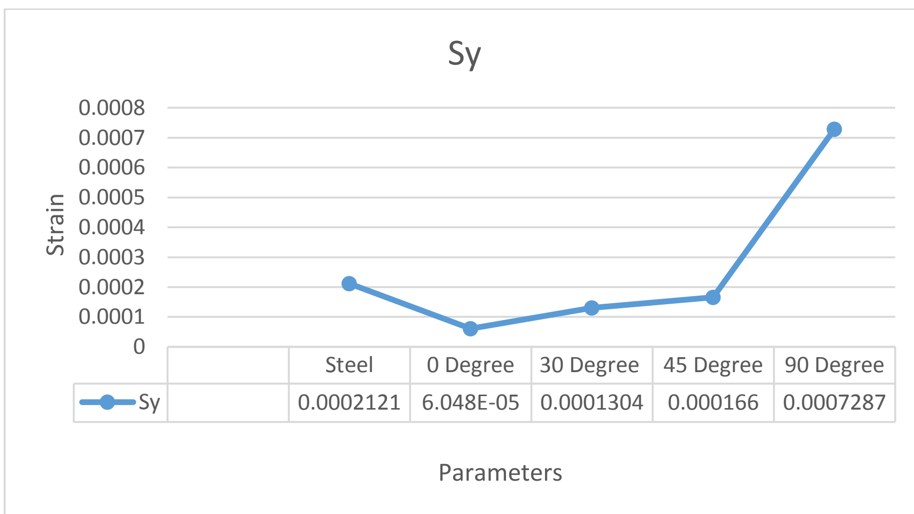
Graph 7. 8 Shear Stress Produced

When shear stresses was seen it was calculated that 64% less was produced at 30 Degree and 62% less at 45 Degree.



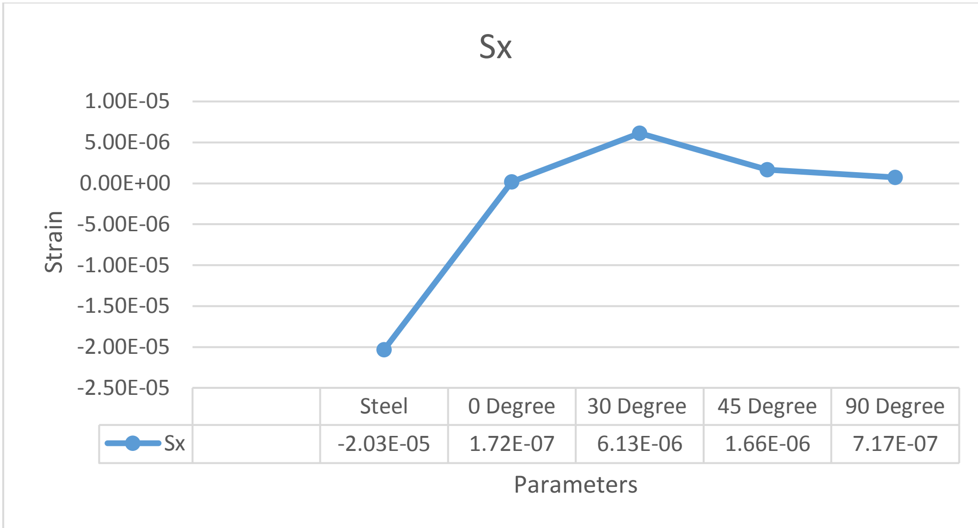
Graph 7. 9 Equivalent Strain Produced

When equivalent strains were seen not much of difference was seen in both the leaf springs.



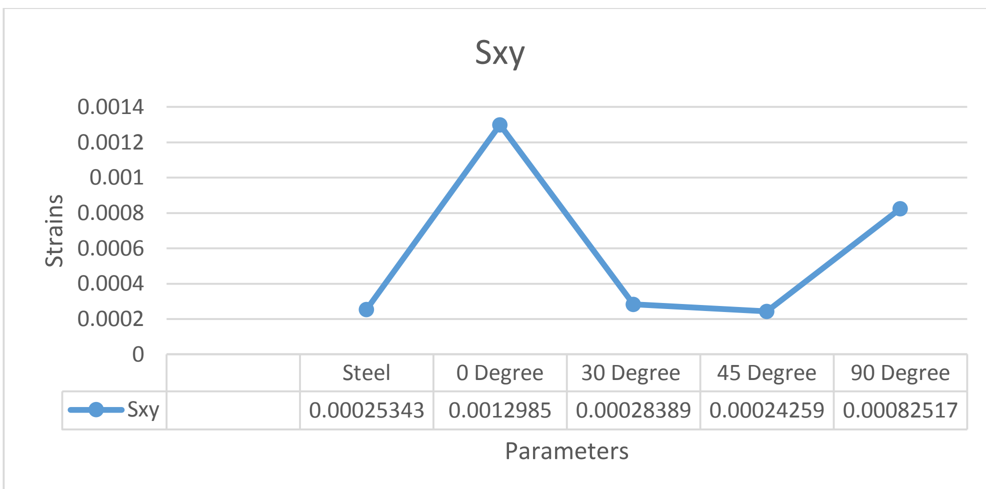
Graph 7. 10 Maximum Strain Produced

Maximum Strains at 0 Degree, 30 Degree and 45 Degree were less as compared to the steel leaf spring.



Graph 7. 11 Minimum Strain Produced

When minimum strains were seen not much of difference was seen in both the leaf springs.



Graph 7. 12 Shear Strain Produced

When equivalent strains were seen not much of difference was seen in both the leaf springs.

Chapter 8

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