iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 9 **Issue:** XI **Month of publication:** November 2021

DOI: https://doi.org/10.22214/ijraset.2021.39000

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue XI Nov 2021- Available at www.ijraset.com

Design Optimization of Leaf Spring Using FEM and RSM

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Abstract: The prime objective of this design and analysis work is to design a Pressure vessel by following the standards of American Society of Mechanical Engineers (ASME). Pressure vessel as a subject matter was opted for the design and analysis with a principal aim to minimize the stress being produced within the structure by structural modification in the Pressure vessel by using analytical approach. ASME (BPVC) Sec-VIII Div- I and Div-II was used to follow the Design by Rule (DBR) and Design by Analysis (DBA) approach. Along with that ASME (BPVC) Sec-II Part- A and Part- D was followed. Cylindrical, Horizontal bullet type Pressure vessel with Hemispherical head was used for this analysis .This work was intended for Stress Minimization within the structure as a principal aim, which is being caused by the exertion of pressure of the fluid on the internal wall and for this SA516Gr65 and SA537 CL 1 material was selected form ASTM Library.

This designed Pressure vessel to be used for the LPG gas storage under the internal design pressure of 1.55MPa at 55°C. The design and analysis work was carried out in two sections Design by Rule (DBR) which is a conventional design, for that empirical formula was used to calculate the value of stress being produced under the given conditions and for the required thickness of the shell, head and nozzle to sustain the applied pressure of fluid by following the standards of ASME (BPVC) Sec-VIII Div- I and Deign by Analysis (DBA), which is a analytical design approach, here Finite Element Method (FEM) was opted for the analysis of the designed model, which was done in the CATIA V5, here in the CATIA two models, Model 1 and Model 2 were created and a structural modification was done in the model 2 and then analysis was performed in the Ansys Workbench 16.0. The comparison was made for both the design approach for the minimized stress values of Hoop Stress and Longitudinal Stress by structural modification and the required thickness under the alternative materials selections criteria was discussed. Up to 25% less stress value was seen in comparative structural analysis of Model 1 and Model 2. This report also discusses the use of SA537 CL 1 material as an alternative options which helps to reduce the thickness of the vessel when compared to the existing materials because this material can sustain the same amount of pressure under given condition at a thinner shell also, this is numerically proved here in this work.

Keywords: Pressure Vessel, ASME, Stress Minimization, LPG, FEM, DBR, DBA, Optimum Design.

I. INTRODUCTION

A. General

Increasing competition and innovation in the automotive industry leads to the modification or replacement of the current goods with new innovative and sophisticated material products. In the current era of fast depletion of natural resources, the primary emphasis among the vehicle manufacturers is to reduce the weight the weight of the vehicles. Less weight is directly proportional to less consumption of the fuel (natural resources) and save energy. Weight loss may be accomplished mainly via the use of innovative mixtures of alternative materials, design optimization, and improved manufacturing methods.

Vehicle suspension systems is yet another field where these advancements are made on a regular basis. More efforts are centered to user's comfort. A satisfactory equilibrium among the comfort and budget in the manufacturing of leaf springs has become the need of the hour. Numerous changes have been already incorporated to the suspension system in last few decades to enhance the productivity in the vehicles. The suspension leaf spring, which accounts for 10% to 20% of the unsprung weight in vehicles, is one of the targeted areas for weight reduction. The consequences of weight reduction are improved fuel efficiency and better ride characteristics of vehicle. The invention of parabolic leaf springs and the usage of composite materials for these springs are some of the most recent suspension system improvements. This addresses the primary focus on the use of composite materials to replace steel from the traditional suspension leaf springs. Steel leaf springs have been revealed to be inferior than composite leaf springs. With less weight and less fatigue, the later has shown better strength and weight-bearing characteristics. They have a higher capacity for storing elastic strain energy.

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Volume 9 Issue XI Nov 2021- Available at www.ijraset.com

The sole stumbling block is the composite structure's complicated structure. The main leaf spring utilised in the research is a part of an electric trolley (used in industries for internal transportation) suspension system. The problem with the available leaf spring was its weight and low fatigue life. To solve the problem, different composite fibres were studied from available literature. Finally a Carbon Fibre Reinforced Polymer (CFRP)composite (woven fibre) material was selected as a material to replace the Steel Society of Automative Engineers (SAE) 5160. In this research work, various models of main leaf spring were designed, analyzed and in last optimized to get better design.

B. Leaf Spring

An elastic body that performs the function of distorting when it is loaded and returns to its initial form when the load is removed is called a spring. Theoretically, a leaf spring is also known as a carriage spring or laminated. It is an elementary kind of spring that is frequently used as suspension in wheel rolled vehicles. In automotives such as heavy duty carriage, light motor vehicles and rail systems, to absorb shock loads leaf springs are primarily utilised in suspension systems.

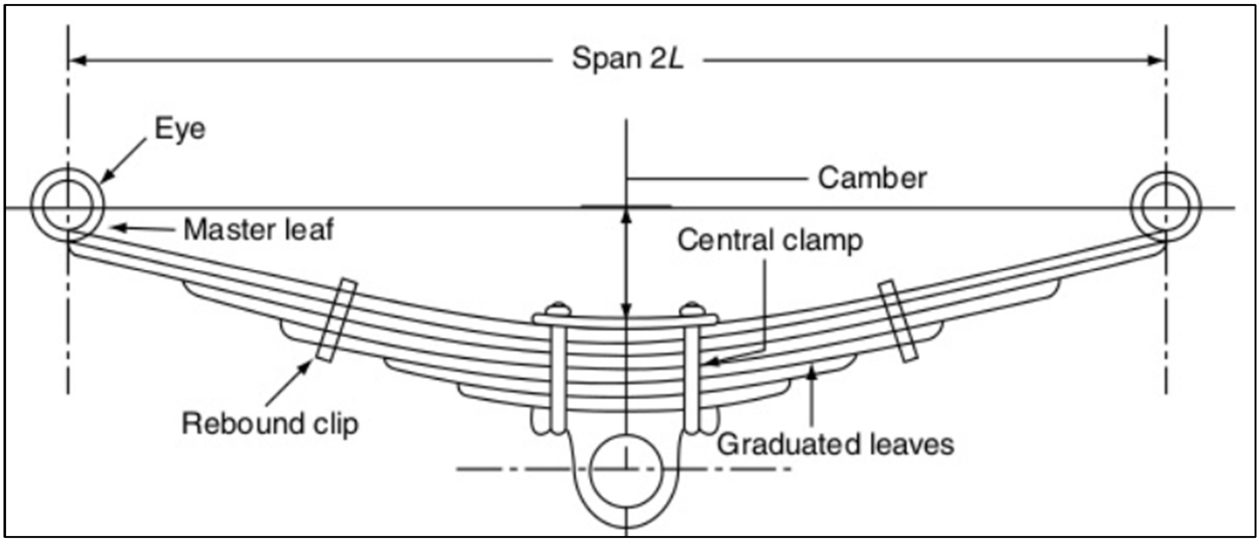

Fig. 1.1: Leaf spring

1) *Construction of Leaf Spring*
a) Semi-elliptical leaf springs are utilised in automotive.
b) These leaves are comprised of a number of plates varying in length.
c) The Master leaf is the main leaf, which is the longest, while all other smaller leaves are called graded leaves.
d) Ubolts are used to secure the spring to the axle.
e) The leaves are held together by rebound clips.
f) The central clampis used to securethe leaf spring to the wheel axle .

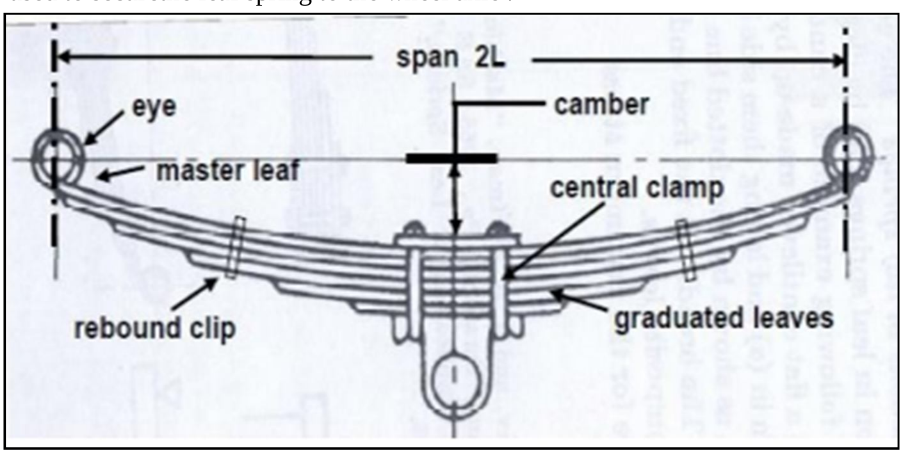

Fig.1.2: Leaf spring parts

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C. Composites

Composites are a broad group of materials that are distinguished by the fact that they are made up of two or more different components. The current study will focus on a kind of composite known as Fiber-Reinforced Plastics (FRP). FRPs are epoxy resin-based composites with fibrous high-strength components. FRPs have great strength and stiffness while being extremely light, and are often used as a substitute for metals in buildings where high performance and low weight are desired. FRPs are often used as low-weight, high-strength materials in the aerospace, automotive, and marine sectors. Both the matrix and the fibre contribute to the durability, making them much more robust than the fibres alone. The fibres on the other hand, have a greater effect on the strength, making them very strong in stress. FRPs are utilised in civil infrastructure for concrete patching, bridge cable reinforcement, and entire bridges. FRPs provide a number of benefits over steel, including the flexibility to adapt the material to the system's demands, corrosion resistance, increased material lifespan and durability, and reduced construction time and cost. Unfortunately, very little long-term testing has been done to determine the materials' ageing properties and limits. Furthermore, the environmental ageing of FRP in the short and long term is yet unknown. The capacity to insert strong stiff fibres in the correct location, in the right orientation, and in the proper volume fraction is the core of fiber-reinforced composite technology

The focus of this study will be on bidirectional reinforced polymers. The fibres in a FRP may take one of two forms: unidirectional reinforcement, in which the fibres are continuous along one direction of the composite, or bidirectional reinforcement, also known as woven, in which the fibres are knitted in a fabric shape and span two directions of the composite.

A composite material may take on a laminar shape, which means it is made up of a certain number of layers, also known as plies or laminates, each of which has a matrix and five fibre constituents. The fibre orientation, as well as the fibre and matrix percentages and materials, may vary from laminate to laminate. The composite material has a specific ply sequence defined by the various fibre orientations in the plies, and all laminates combined make up the laminate or ply stack (Fig. 1). The final characteristics of the composite structure are determined by the ply, or stacking, sequence, volume percentages of the components, and number of laminates in the laminate. The number of plies may be even or odd, resulting in anti-symmetric or symmetric laminates (Fig. 2), which will influence the composite structure's performance and characteristics.

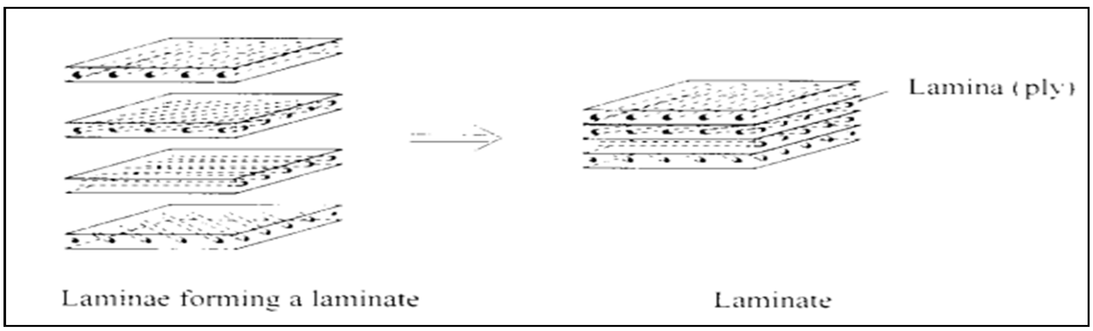

Fig.1.3: Laminate composites

II. LITERATURE REVIEW

A. Literature Review

1) James N Foote et al. (2016) Controlled shot peening is well known and acknowledgedas a method of increasing fatigue strength, according to the findings. The majority of the research ignores the impact of internal damping under different shot peening settings. Dampening thought will lead to a better grasp of the actual causes for the apparent decrease in fretting weariness. The majority of studies focused on improving fatigue life via shot peeing, which imparts compressive residual stress in the material's top layer, complicating the nucleation and propagation of fatigue fractures. The majority of them used the fracture mechanics model, while a few [3, 34, 42, 54, 67, 90, 120] tried to increase fatigue life using the stress approach model. Researchers that are interested in fatigue behaviour attempted to determine the impacts of surface roughness. The importance of surface roughness when evaluating the surface contact between two bodies cannot be overstated. Because crack initiation is influenced by surface characteristics, the local stress field created by surface roughness is critical. There may be goals of infinite life, zero weight, infinite strength, or 100 percent dependability when designing any mechanical component for fatigue failure, or even all four at the same time. After shot peening, a component's fatigue life improves, which raises additional problems such component design, size, and material, which should be changed for economy and efficiency [3,27,51,63,84,90,110]. Designers prefer accurate fatigue estimates for real components, although they are still susceptible to errors.

2) Taehong Kim et al. (2019) The impact of leaf form was studied using a semi-analytic model based on Euler beam theory and a FEM model. The position of contact points changes as the form of the leaf changes. Experiments have indicated that the noise is caused by a tiny collision between the leaves, based on this study. In order to examine the impact of shape change, the Euler beam model is found to be more effective.
3) Pagani, A., R. et al. (2019) The static and dynamic behaviours of composite leaf spring landing gears during the landing phase of an aeroplane are investigated in this article. In order to assess the forces that occur on the fuselage during the impact of the aircraft on the ground, an exact simulation of the entire landing gear system must be conducted. The Finite Element Method (FEM) was used to create a model of the leaf spring landing gear, which was then used to evaluate its motion using a Multibody Simulation (MBS). The findings illustrate how straight and curved leaf springs transfer force to the fuselage. In order to assess design sensitivity, several thickness and material values were considered. Finally, graphs and tables depict the connection between the geometry and material properties of composite landing gear and the force on the fuselage, which may be utilised in future landing gear design and development.
4) Loganathan, et al. (2020) In order to reduce fuel consumption and improve efficiency, the automotive and aviation industries are looking for a superior alternative material that has excellent specific strength, is light in weight, and is extremely durable. The automobile leaf spring is a component that promotes vehicle dynamics and, as a result, travel comfort by providing the necessary stiffness. The study of automobile leaf springs in terms of material change from conventional SAE 5160 steel (Chromium steel) to CFRP (Carbon Reinforced Polymer Composite) to achieve significant strength, associated weight reduction with reduced fuel consumption, and improved vehicle performance is the focus of this work. The findings of flexural fatigue life and damage suffered for both materials are presented in this paper using FE Analysis. Various ply orientations are also taken into account in order to improve the fatigue life of composite materials.
5) Raju, B. et al. (2020) Leaf springs are a kind of spring that is utilised in car suspension systems. A leaf spring's primary purpose is to sustain vertical loads while also isolating road-induced vibrations. A typical leaf spring design from a commercial small load carrier vehicle was selected for research in this project. The research is looking for a novel leaf spring material. Materials such as Silicon Manganese Steel, Carbon Fiber, Silicon Carbide, Co-Cr-Ni alloy, Al oxide (99% alumina), and Beryllium Alloy are compared to standard materials to determine their compatibility. SOLIDWORKS is used to model the leaf spring, while ANSYS 16.0 Workbench is used to perform static analysis. The goal of this research is to compare the stresses and deformation of different types of materials. Different materials are subjected to static analysis and compared to one another in order to find the best material for manufacturing. Carbon fibre, when compared to other materials, has superior characteristics, according to the findings of the static study. Furthermore, the loading circumstances and material selection have a significant impact on the functioning of the leaf spring. As a consequence, the Taguchi technique may be used to verify the findings obtained for the material Carbon fibre. Carbon Fiber, which is a composite material, may be regarded an excellent material for the building of leaf springs, according to the total static analysis and validation via the Taguchi Method.

B. Research Gap

Based on the above history and literature, as well as research articles by various researchers and professionals, it has been determined that there are some areas in which research has not been focused in relation to leaf springs, and it has been proposed to focus on those areas with this current work.

The research gaps discovered throughout the literature evaluation are as follows:

1) Many different types of composite materials are used for replacing steel leaf spring but woven fibre i.e. bidirectional fibres reinforced polymer composites are comparatively not evaluated properly whereas these woven fibres eliminates the problem of chipping of outer layer of composite fibres in leaf spring application and can play an important role in solving the weight problem of metallic leaf spring.
2) Very few researchers have considered the impact of more than one variables in designing the leaf spring, mostly mass was reduced by using new material but various other factors like fatigue life etc are not taken into considerations which is very important while replacing one material with another.
3) A small number of researchers focused on using computer optimization techniques like RSM etc to optimize different leaf spring design characteristics.

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.429
Volume 9 Issue XI Nov 2021- Available at www.ijraset.com

C. Research Objectives

The following are the primary goals for this research project:

1) Minimizing the weight of spring
2) Cost saving
3) Optimized design

The above-mentioned research goals may be met by altering the leaf spring design, as well as the material and/or material characteristics of the leaf spring. The advantages that may be gained by fully completing this study effort are as follows:

Material and time saving

a) Precision & Accuracy
b) New and improved design
c) Increased analysis speed

III. METHODOLOGY

A. Research Design, Procedures and Tools Used

After selection of material, various softwares were used in a sequence to get the desired outcome. As described earlier, CATIA was used for CAD Modeling of all leaf spring models (described in chapter 4). Ansys was used for modeling and simulation work. Response Surface methodology software "Design Expert" is used for optimization of leaf spring.

After CAD modeling, all models are imported from CATIA to ANSYS Software. ANSYS software works on the principle of Finite Element Analysis (FEA). FEA is a numerical technique which is mostly used to get the approximated result by the solution of partial differential equations which is developed by using various boundary conditions, external applied loads etc. A comprehensive layout of the modeling part in ANSYS is shown in figure 3.2.

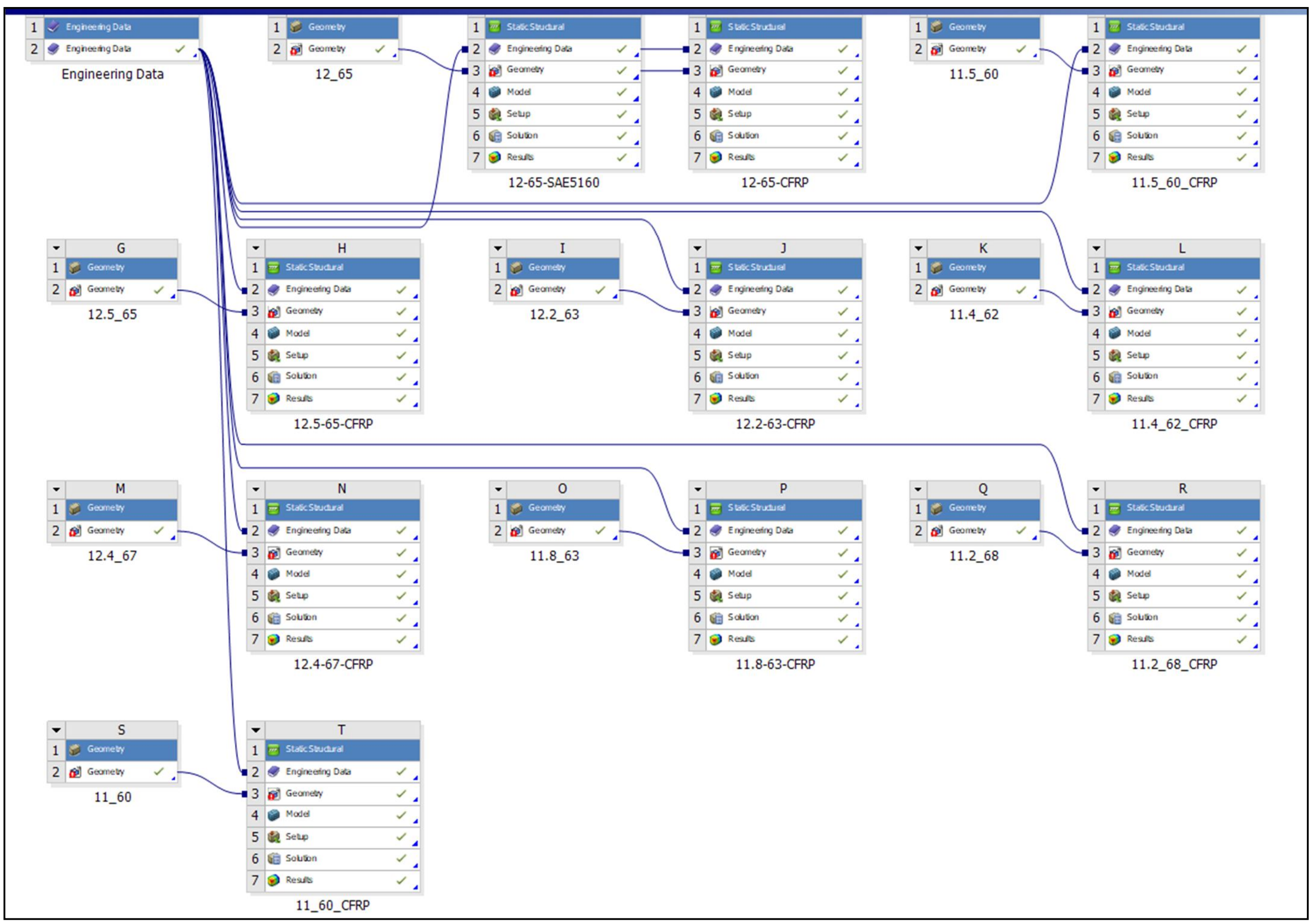

Fig3.2: layout of the modeling part in ANSYS

In our study FEA has been done in simulation software ANSYS workbench 2021R1 for steel as well as Carbon Fibre Reinforced Polymer (CFRP) springs.

ANSYS modeling is divided into mainly 3 parts:
1) Modeling (Pre-processing)
2) Ansys workbench solving/Analysis of results
3) Post processing (interpretation of results)

The detailed work of modeling and Analysis is discussed in chapter 4.
For optimization part, Response Surface Methodology (RSM) is used as it conducts large number of experiments in a very short span of time which enables researchers to save time and money. RSM is world recognized statistical and mathematical tool which calculates the effect of various factors on the certain number of responses of interests. It is a tool which calculates and identifies the optimal responses by doing various numbers of experiments in short span of time. In this research, Design Expert Software used the ANSYS results data to optimize the design of Leaf Spring. Width and thickness of leaf spring are optimized through RSM technique considering various constraints of responses chosen i.e fatigue life, deflection, Von misses stress, mass etc.
For optimization through RSM, firstly we need to identify the independent factors and responses variables. Independent factor's lower and upper limit should be inputted in Design Expert software with respect to which alpha and face values of factors will be decided by software itself. Selection of responses is equally important as responses will play very important role in optimizing the factors. In this research work, width and thickness are taken as independent factors and 4 parameters i.e. stress, displacement (deformation), fatigue cycle and mass of leaf spring models are considered as responses. All the experimental data required for modeling of various RSM model in Design expert software is taken from the result part of ANSYS model. Values of all 4 responses with respect to independent factors are taken and inputted to create mathematical model for all the responses. Model selection (linear, quadratic, 2F1, cubic) is done on the basis of ANOVA, F test, Adjusted and predicted R^2 values difference and adequate precision ratio. After selection of particular model for all responses, mathematical equations are derived in terms of actual factors and coded factors. Modal graphs can also be generated using Design expert software.
A flow diagram describing the processing of RSM is shown in figure 3.3

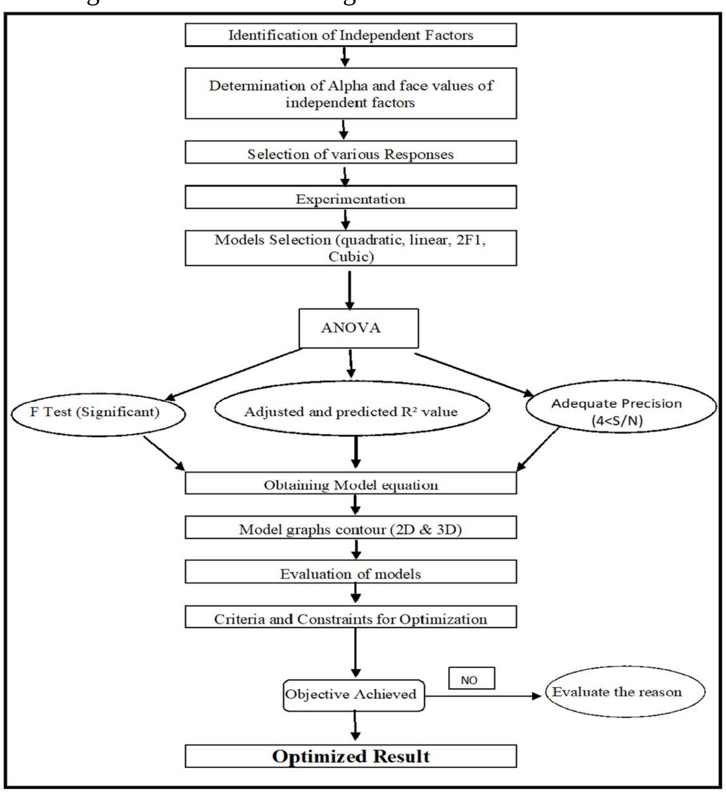

Fig 3.3: Flow Diagram Describing the Processing of RSM

Equations of responses generated in RSM modeling in terms of actual factors are:

- **Stress Max** =1026.45160 - 46.41854*thickness -3.29042*width,
- **Displacement** = +1.05015 - 0.107720*thickness - 0.006903*width - 0.000360*thickness*width + 0.004802*thickness^2 +0.000080*width^2
- **Fatigue Cycles** = 1904000 + 756800 * thickness + 377000 * width
- **Mass** = -1.11125 + 0.111256 * thickness + 0.015213 * width + 0.003718* thickness * width - 0.006154* thickness^2 - 0.000157* width^2

After obtaining mathematical equations and models for all the responses, various constraints are set for all the responses to optimize the independent factors.
In this part, design expert software conducts various numbers of experiments (109 in this research) considering random values of independent factors (width and thickness) within range to get the optimized solution. A detailed discussion of RSM modeling and optimization is discussed in chapter 5.

B. Data Analysis
The results obtained from ANSYS are used in RSM software for creation of mathematical modeling of selected responses. Various statistical tools like ANOVA (Analysis of Variance), standard deviation etc are examined for obtained ANSYS data. Subsequently results of all 9 models of CFRP composites are analyzed and compared separately with result data of Steel leaf spring. The data analysis is done through various bar graphs and charts which are explained in chapter 6. Main outcomes of the analysis are:

1) Maximum Stresses developed in all CFRP leaf springs are compared with the help of bar graphs.
2) Masses of all 9 CFRP leaf springs are compared to the steel leaf spring mass.
3) Deflection and Fatigue cycle in all leaf springs is compared and analyzed using charts.
4) All these parameters of optimized CFRP leaf spring is compared with existing SAE5160 Steel leaf Spring.

IV. MODELING AND ANALYSIS

A. Drafting of Leaf Spring Models
Drafting of the Leaf models is carried out in Computer Aided Three-dimensional Interactive Application (CATIA) software which is multi platform for Computer Aided Engineering (CAE), 3D Modelling, Computer Aided Design etc.
CATIA is a French company Dassault Systems developed software and is mostly preferred in design analysis as it supports multiple stages of product designing and development be it in initial stages of drafting or final stage of analysis. But in our study, we have used CATIA as drafting software only and created 9 models of leaf springs varying in thickness and width.

B. Finite Element Modeling and Analysis
The Finite Element Analysis is a numerical technique which is mostly used to get the approximated result by the solution of partial differential equations which is developed by using various boundary conditions, external applied loads etc. In our study Finite element analysis has been done in simulation software ANSYS workbench 2021R1 for steel as well as Carbon Fibre Reinforced Polymer (CFRP) springs.
Ansys workbench 2021 is recently developed version. As mentioned earlier, these simulation softwares works on Finite Element Analysis techniques which is nothing but a mathematical representation of physical system comprising model, material properties , boundary conditions. All these are parts of pre-processing only. Similarly working of Ansys is divided into 3 main parts which is

1) Modeling (Pre-processing)
2) Ansys workbench solving/Analysis of results
3) Post processing (interpretation of results)

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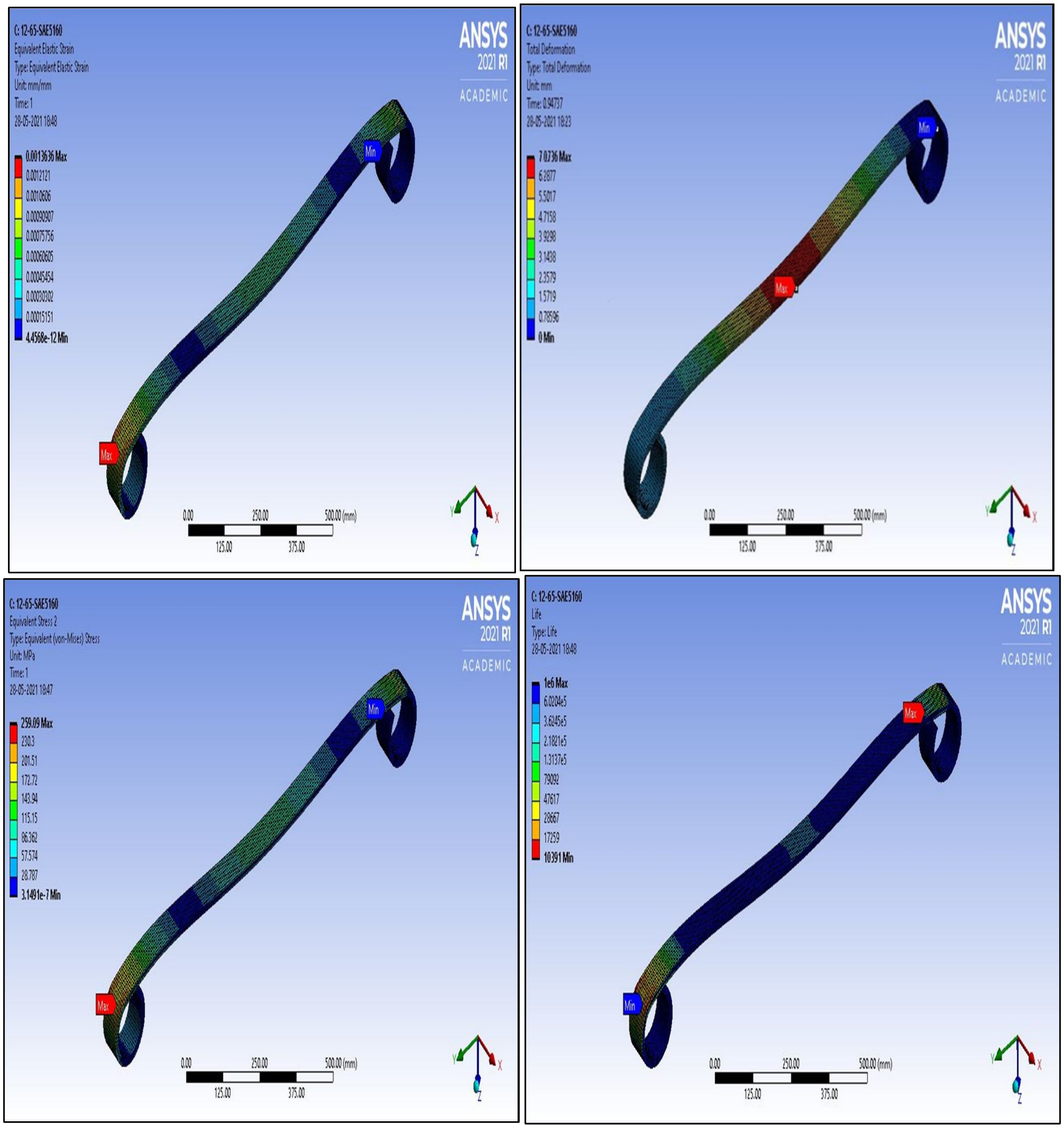
C. Result of Steel SAE5160 leaf Spring Model



- Mass-11.1033 Kg
- Stress max259
- Fatigue life1.00e+006 cycles
- Deformation 0.07 m
- Equivalent Strain 0.00136

Fig: 4.7 Analysis of Steel SAE5160 leaf spring (Deformation, Stress, Strain and Fatigue life)

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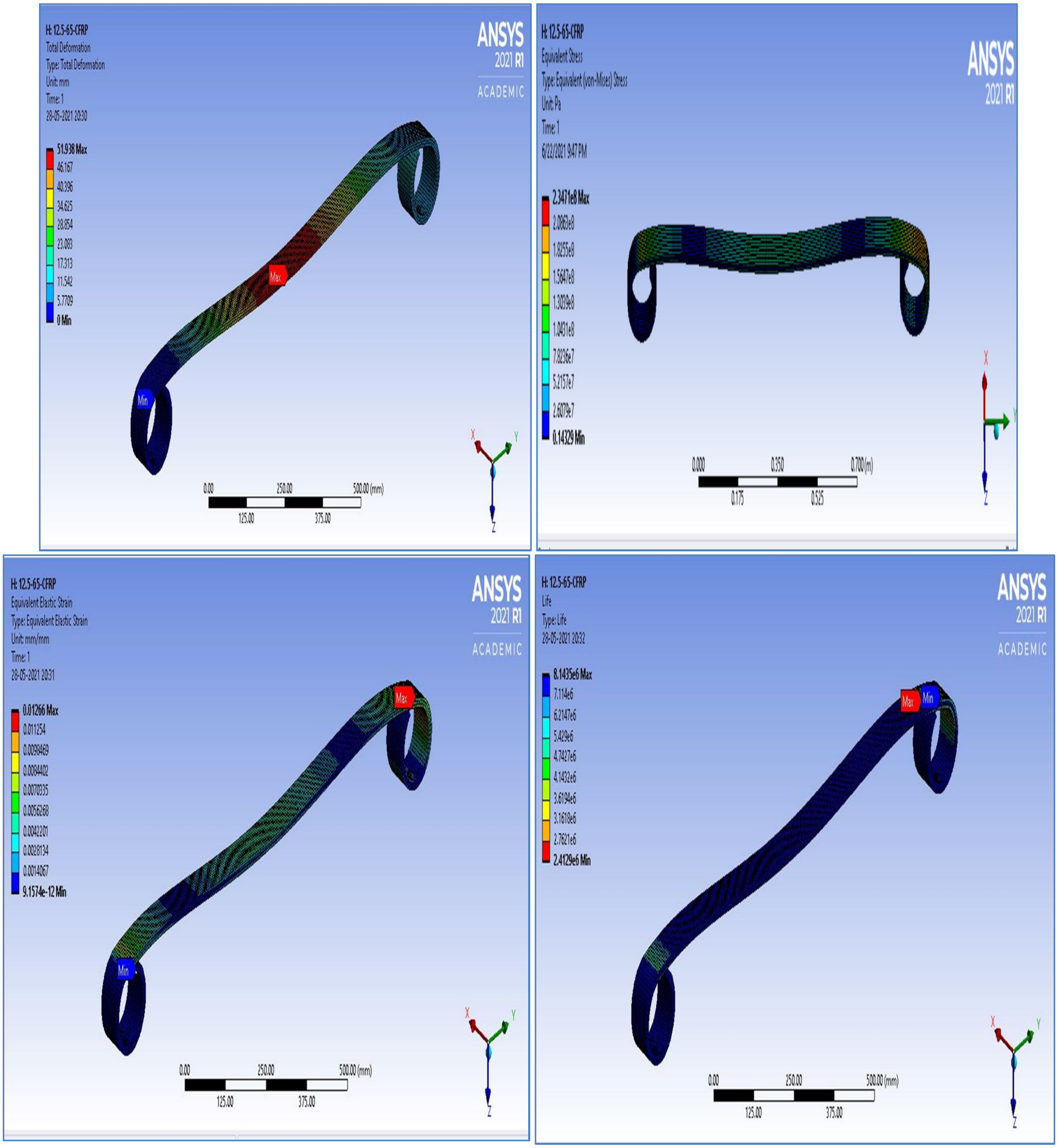
D. Result of Carbon Fibre Reinforced Polymer 12.5_65 Model



- Mass-2.6634 Kg
- Fatigue life-2.4129e+006 cycles
- Equivalent Strain-0.01260
- Stress max-235
- Deformation-0.0519 m

Fig: 4.10 Analysis of CFRP 12.5_65 Model leaf spring (Deformation, Stress, Strain and Fatigue life)

E. Result Matrix of all Models

There are 10 models for which FEM analysis is performed.

The table no. 4.3 shows the results obtained by using Ansys WorkBench 2021 R1. The various parameters dealt under the study are stress max (Von-Misses stress), Fatigue life (minimum no. of cycles before failure), Deformation, Equivalent strain, masses of spring.

Table no 4.3: Results of various parameters in all models of Leaf Spring by Ansys

Sl. No	Models	Material	Mass (Kg)	Stress max (M. Pa)	Fatigue life (min)	Deformation	Equivalent Strain max
1	12_65 SAE5160	SAE 5160	11.1033	259	1.00e+006 cycles	0.070 m	0.00136
2	12_65 CFRP	CFRP	2.5623	254	2.0039e+006 cycles	0.0585m	0.01370
3	12.5_65 CFRP	CFRP	2.6634	235	2.4129e+006 cycles	0.0519m	0.01260
4	12.4_67 CFRP	CFRP	2.7242	231	2.501e+006 cycles	0.0516m	0.01240
5	12.2_63 CFRP	CFRP	2.5218	254	2.0051e+006 cycles	0.0577m	0.01360
6	11.8_63 CFRP	CFRP	2.4420	267	1.7794e+006 cycles	0.0640m	0.01430
7	11.5_60 CFRP	CFRP	2.2666	295	1.4068e+006 cycles	0.0728m	0.01580
8	11.4_62 CFRP	CFRP	2.3246	290	1.4615e+006 cycles	0.0723m	0.01560
9	11.2_68 CFRP	CFRP	2.5018	284	1.5471e+006 cycles	0.0737m	0.01530
10	11_60 CFRP	CFRP	2.1681	322	1.0327e+006 cycles	0.0835m	0.01730

V. CONCLUSION

A. ANSYS Results verses Analytical model calculation

Deformation parameter is also checked for both the models and there was 10-12 percent variation which may be because of different approaches and various assumptions taken during development of both the models (like Leaf is semi-elliptical shape but considered as straight cantilever beam while developing Analytical model). Also as FEM is a statistical tools which calculates approximate values, it is absolutely clear that the Ansys model is perfectly developed.

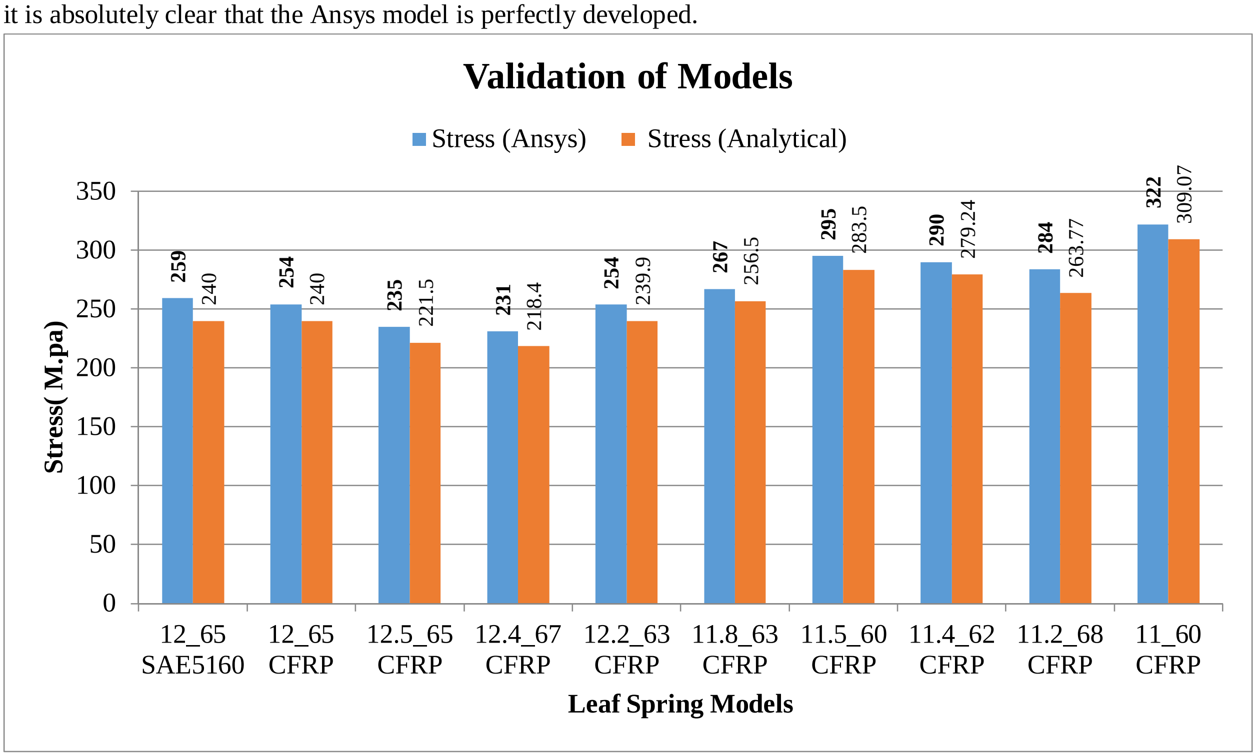


Fig. 5.1 Bar-graph representation of Analytical stress and Von Misses stress (ANSYS).

B. Deformation

Deformation in all the leaf springs are compared and it is found that deformation in CFRP is less as compared to steel leaf spring for the same dimension which convey that CFRP composite is stiffer and harder than that of steel and can replace it very well but the ride quality will be on stiffer side although difference in deformation is not so much.

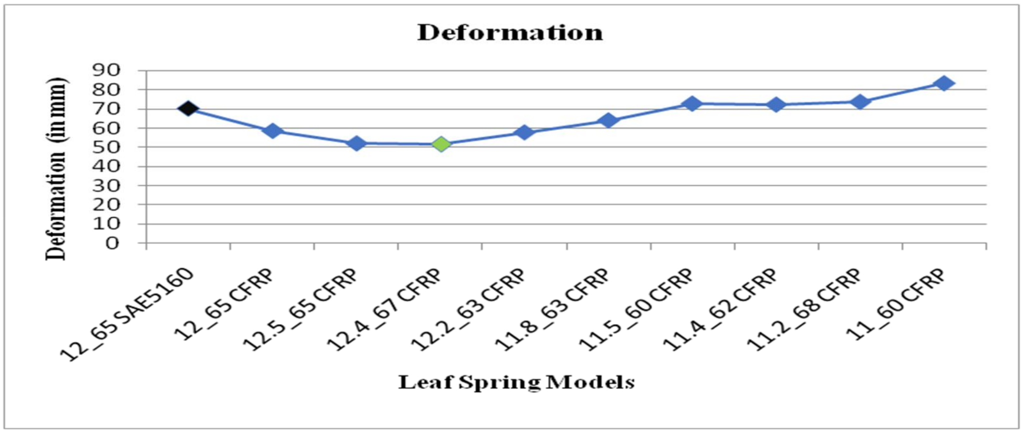


Figure 5.2- Deformation in all leaf spring Models

C. Stress Maximum

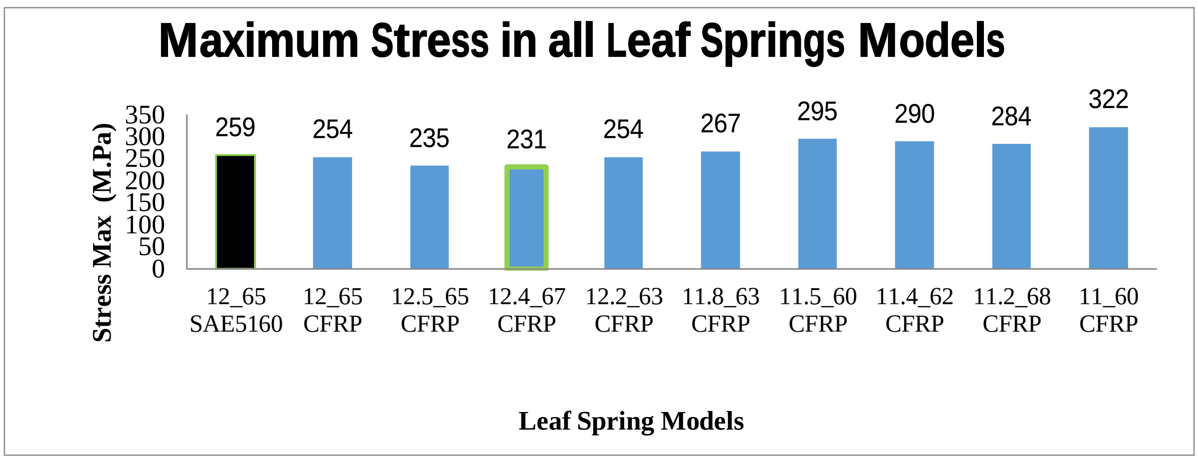


Fig 5.3: Max Stress induced in all Leaf Spring Models.

D. Fatigue Life

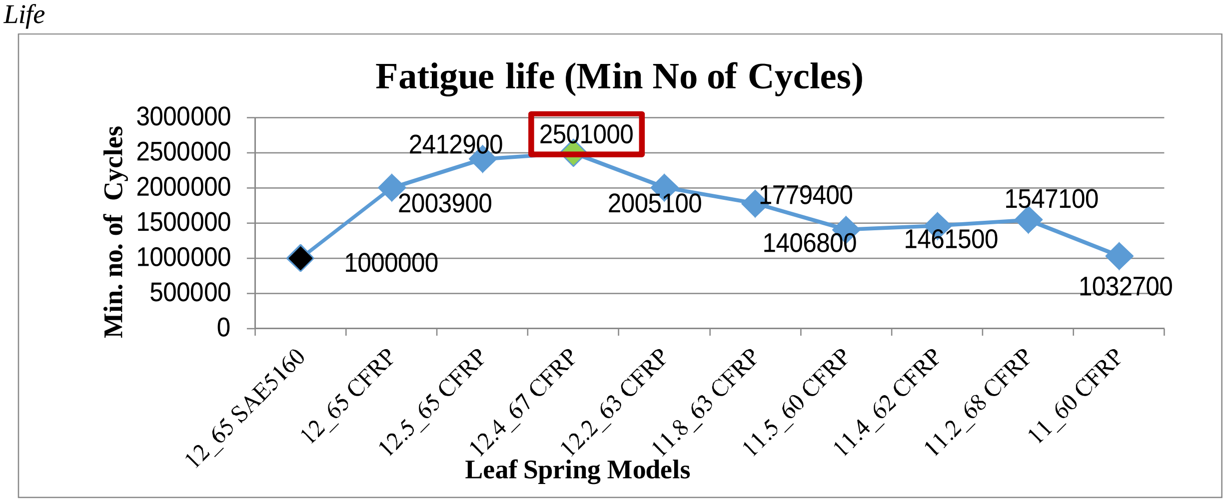


Fig5.4: Fatigue life of all Leaf Spring Models.

E. Mass of all Leaf Spring Model

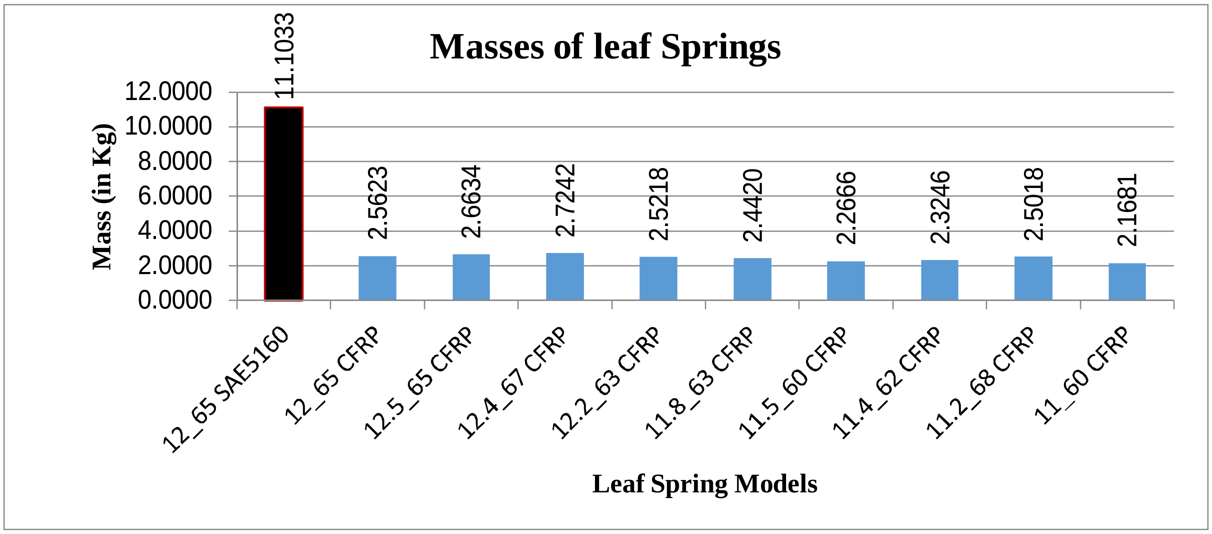


Fig 5.5: Mass of all Leaf Spring Models.

REFERENCES

[1] Mahmood M. Shokrieh , Davood Rezaei " Analysis and optimization of a composite leaf spring " Composite Structures, 60 (2003) 317–325.

[2] E. Mahdi a, O.M.S. Alkoles a, A.M.S. Hamouda b, B.B. Sahari b, R. Yonus c, G. Goudah " Light composite elliptic springs for vehicle suspension " Composite Structures, 75 (2006) 24–28.

[3] Y. N. V. Santhosh Kumar, M. Vimal Teja " Design and Analysis of Composite Leaf Spring " Dept. of Mechanical Engineering, Nimra College of Engineering & Technology, Ibrahimpatnam, Vijayawada. (2012)

[4] Pankaj Saini, Ashish Goel, Dushyant Kumar " Design and analysis of composite leaf spring for light vehicles " International Journal of Innovative Research in Science, Engineering and Technology Vol. 2, Issue 5, May 2013.

[5] Manas Patnaik, Narendra Yadav, Ritesh Dewangan " Study of a Parabolic Leaf Spring by Finite Element Method & Design of Experiments "International Journal of Modern Engineering Research Vol.2, Issue 4, July-Aug 2012 pp-1920-1922 .

[6] Malaga. Anil Kumar , T.N.Charyulu, Ch.Ramesh " Design Optimization Of Leaf Spring " International Journal of Engineering Research and Applications Vol. 2, Issue 6, November- December 2012, pp.759-765.

[7] Prahalad Sawant Badkar, Prahalad Sawant Badkar " Design Improvements of Leaf Spring of BEML Tatra 815 VVNC 8 X 8 Truck " International Journal of Emerging Technology and Advanced Engineering ,Volume 3, Issue 1, January 2013.

[8] H.A.AI-Qureshi " automobile leaf spring from composite materials " Journal of materials processing technology, 118(2001).

[9] Ashish V. Amrute, Edward Nikhil karlus, R.K.Rathore "design and assessment of multi leaf spring'' International journal of research in aeronautical and mechanical engineering, ISSN :2321-3051. November (2013).

[10] Hawang, W., Han, K. S.,"Fatigue of Composites – Fatigue Modulus Concept and Life Prediction", Journal of Composite Materials, 1986.

[11] Dharam, C. K.,"Composite Materials Design and Processes for Automotive Applications", The ASME Winter Annual Meeting, San Francisco, 1978.

[12] AL-Qureshi, H. A.,"Automobile leaf springs from composite materials", Journal of Processing Technol., 2001.