Fatigue analysis of composite material parabolic leaf spring through S-N approach using FEA

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Abstract -This work is carried out on a parabolic leaf spring of a TATA ACE mini loader truck, which has a loading capacity of 750kg. The modelling of the parabolic leaf spring has been done in Creo-2.0. And for finite element analysis the parabolic leaf spring model was imported in the static structural analysis workbench of ANSYS-14 software. Life of spring, damage ,fatigue safety factor,fatigue sensitivity of the parabolic leaf spring are the output parameters of this fatigue analysis. parabolic leaf spring is a very important element in automobile suspension system, To overcome of this work, steel parabolic leaf spring is replaced with the composite material parabolic leaf spring. use of composite material the weight of the spring decreases without an increase in cost and a decrease in quality and reliability.

Keywords: composite parabolic leaf spring,weight reduction,fatigue life, FEA.

1 INTRODUCTION

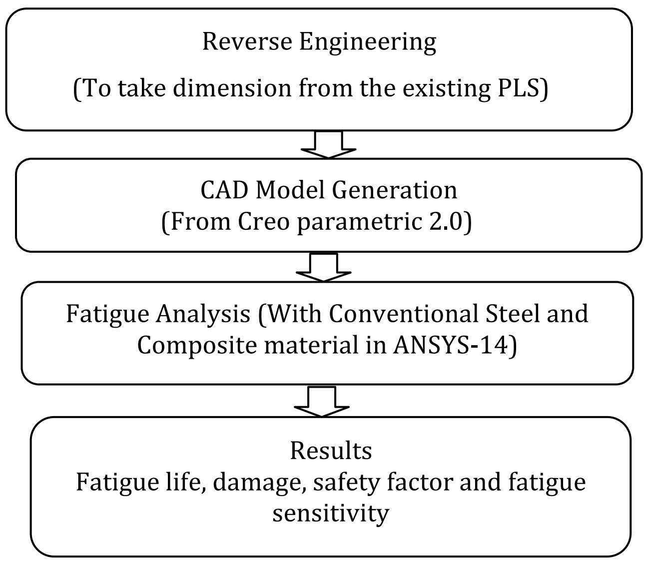
1.1 Background of the research work

This work is carried out in two parts, the first part deals with geometric CAD modeling of a parabolic composite leaf spring with construction details, and the second part deals with the analysis of the parabolic leaf spring, by using ANSYS-14 software. ANSYS software is used for general purpose finite element analysis and for numerically solving mechanical problems. Here ANSYS- 14 is used for analyzing the performance of conventional steel EN45 and composite parabolic leaf spring. Leaf spring is modeled in Pro-Engineering creo-2.0 software and it is imported in ANSYS- 14. The conventional steel parabolic leaf spring and the composite parabolic leaf spring were analyzed under similar loading and boundary conditions using ANSYS-14 software and the results are presented. Static analysis determines the safe stress and corresponding payload of the parabolic leaf spring and also studies the behavior of structures under practical conditions. The present work attempts to analyze the safe load of the parabolic leaf spring. Maximum displacement, equivalent stress, strain energy, maximum principle stresses, and weight of the assembly are the output targets of this analysis for comparison and validation of the work. For fatigue analysis, the S-N approach is used to predict the fatigue life and damage of conventional steel parabolic leaf springs and composite parabolic leaf springs.

Parabolic leaf springs are the components of the suspension system, they perform isolation tasks in transferring vibration due to road irregularities to the driver's body. Increasing competition and innovations in the automobile sector tend to modify the existing products and replace old products with new and advanced material products, more efforts are taken in order to increase the comfort of users and improve the suspension system, and hence many modifications have taken place over time. Inventions of parabolic leaf springs and the use of composite materials, for these springs are some of the latest modifications in the suspension system. The main advantages of parabolic leaf springs are that they are lighter, cheaper, and have better fatigue life. And they isolate more noise. CAE tools are widely used in the automobile industry for modeling and analysis of automobile parts.

2 METHODOLOGY

For achieving the objective of the research work a flow chart is prepared which shows various steps taken in to consideration.



3. FATIGUE ANALYSIS OF THE PARABOLIC LEAF SPRING

3.1 Introduction

In this simulation, the Goodman approach, Soderberg's theory, Gerber's theory, and mean stress curves have been used. The material that has been used for the simulation of the parabolic leaf spring is conventional steel EN45 and composite material (E-glass/epoxy, carbon/epoxy, Kevlar/epoxy). The results were obtained using ANSYS -14 software. The results are compared and the theory which gives the lowest value of life and the highest value is chosen to be best in the analysis of steel EN45 and composite parabolic leaf springs Loading data is chosen as history data of SAE transmission and is applied. Life data analysis: This is carried out by applying a load of 500 to 5600N and the analysis is carried out by the above-mentioned four approaches. Goodman's and Gerber's approach: Using Gerber's theory the life data obtained is similar to Goodman's theory. Mean stress theory approach: Using mean stress curves, this theory is not preferred for the life data analysis of the parabolic leaf springs.

ASSUMPTIONS

Conventional steel EN45 parabolic leaf spring and composite parabolic leaf spring (E-glass/epoxy, carbon/epoxy, Kevlar/epoxy) are modeled with constant width and varying thickness design.

1. The constraints parameter i.e. dimensions and boundary condition of steel parabolic leaf springs is the same as that of composite parabolic leaf springs.

2. Fatigue life prediction of parabolic leaf spring based on finite element analysis using Stress life approach.

Stress-life Data Options/Features in ANSYS-14

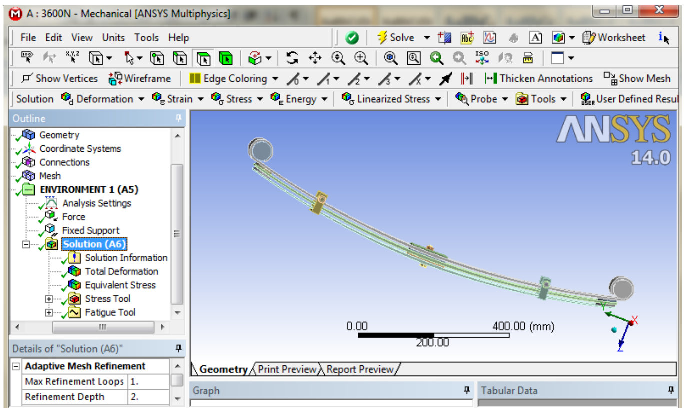


Figure 3.1 is a screen shot showing a user editing fatigue data in ANSYS

3.2 Post-processing

A fatigue analysis can be separated into 3 areas: materials, analysis, and results evaluation. Each area will be discussed in more detail below.

3.2.1 Materials

A large part of a fatigue analysis is getting an accurate description of the fatigue material properties. Since fatigue is so empirical, sample fatigue curves are included only for structural steel. These properties are included as a guide only with intent for the user to provide his own fatigue data for more accurate analysis. In the case of assemblies with different materials, each part will use its own fatigue material properties just as it uses its own static properties (like modulus of elasticity).

3.2.2 Analysis

Fatigue results are often added before or after a stress solution has been performed. to make fatigue results, a fatigue tool must first be inserted into the tree. this will be done through the solution toolbar or through context menus. the small print view of the fatigue tool is used to define the various aspects of a fatigue analysis such as loading type, handling of mean stress effects, and more. As seen in Figure -3.2, a graphical representation of the loading and mean stress effects are displayed when a fatigue tool is chosen. this will be very useful to help a novice understand the fatigue loading and possible effects of mean stress.

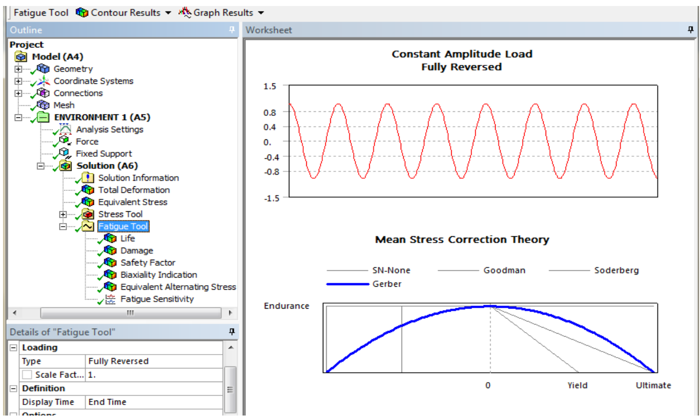
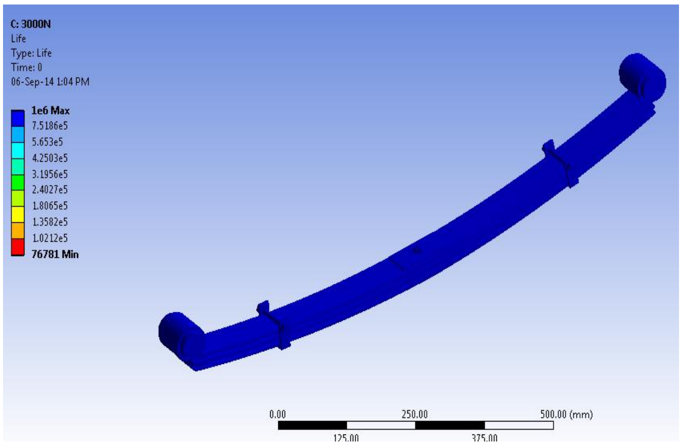
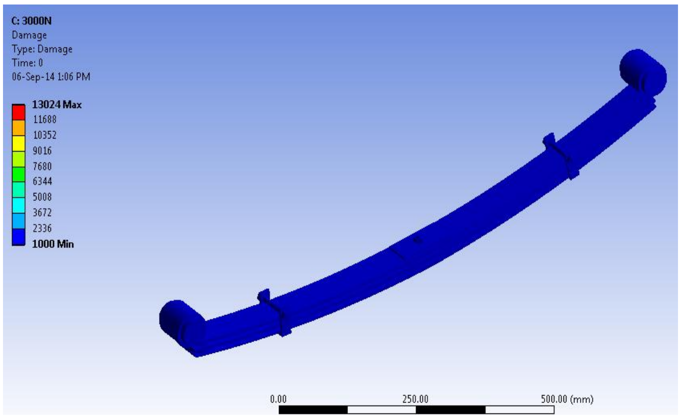


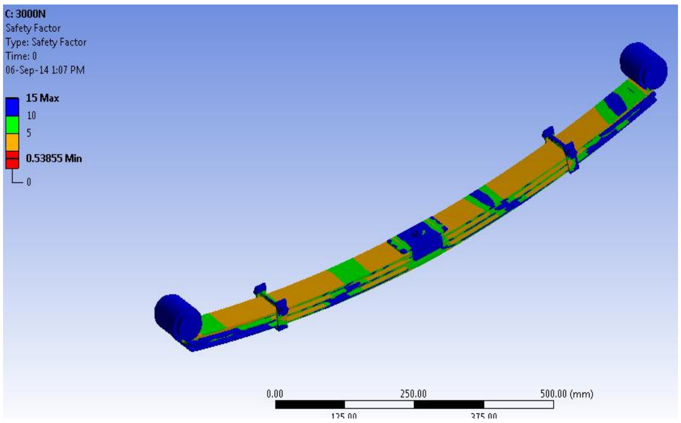
Figure- 3.2show loading type and handling of mean stress effects

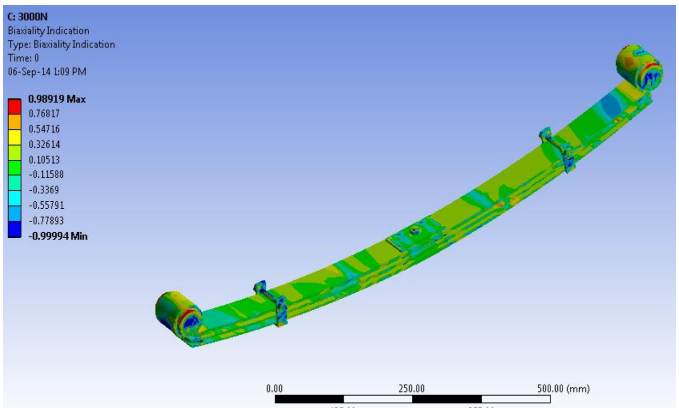
3.2.3 Results Output

Several results for evaluating fatigue analysis are available, Outputs include fatigue life, damage, factor of safety,fatigue sensitivity, each output will now be described in detail.









4 FATIGUE ANALYSIS RESULTS

4.1 Life

The data obtained from the analysis work is used to generate the fatigue strength factor vs. the S-N diagram. Fatigue strength is an expression used to describe a property of material, the stress at which failure occurs for a given number of cycles is the fatigue strength. Fig-4.1 shows the life cycle of the composites and steelEN45 material at 5600N for different-different fatigue strength factors. It is observed that the fatigue life of all parabolic leaf spring materials is low when the fatigue strength factor value is low. The life cycle of the parabolic leaf spring increased gradually up to a fatigue strength factor is 0.65, when the fatigue strength factor increases beyond 0.65 the life cycle of E-glass/epoxy and carbon/epoxy increased at a high rate as compared to steelEN45. The maximum life of Kevlar/epoxy, steelEN45, carbon/epoxy, E-glass/epoxy at 5600N and fatigue strength factor value is 1 life is 3516, 5163, 8155, 8365 respectively. And minimum life occurs in part no. 8 of the parabolic leaf spring.

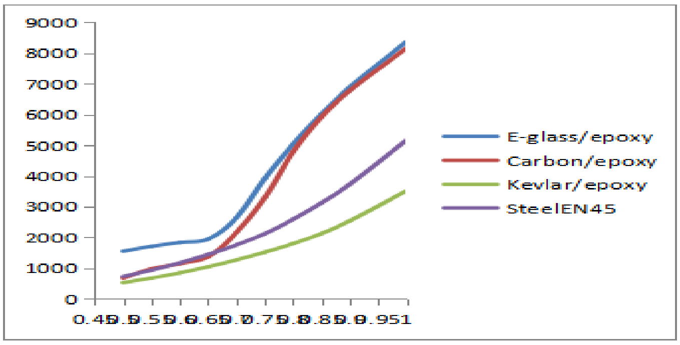


Figure- 4.1 Life vs fatigue safety factor

4.2 Damage

A damage test for the parabolic leaf spring has been done using the ANSYS-14 fatigue tool, fully reversed load 5600N is applied, and mean stress theories are also used. The Goodman theory is often a good choice for brittle materials with the Gerber theory usually a good choice for ductile materials. Fatigue Damage may be a contour plot of the fatigue damage at a given design life. Fatigue damage is defined because the design life is divided by the available life. This result could also be scoped. The default design life could also be set through the Control Panel. For Fatigue Damage, values greater than1indicate failure before the planning life is reached. the utmost damage of E-glass/epoxy, carbon/epoxy, Kevlar/epoxy, steelEN45 at fatigue strength factor is 0.5 is 6.4416e5, 7.8490e5, 1.8863e6, 1.3654e6 respectively. The results obtained 0.5 and 1 fatigue strength factor is shown below.

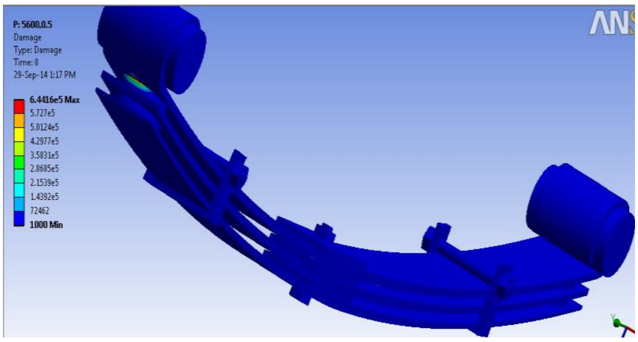


Fig.4.2 shows fatigue damage of e-glass/epoxy at 5600N fatigue strength factor is 0.5

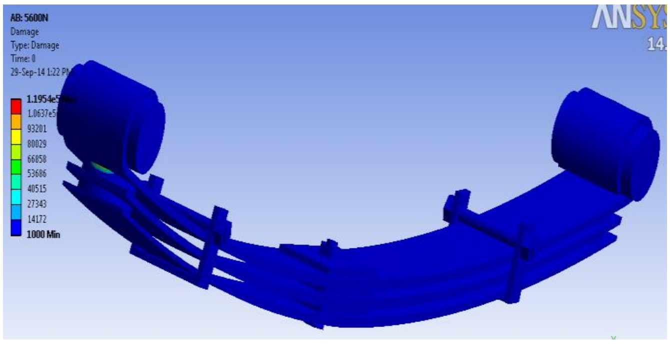


Fig.4.3 shows fatigue damage of e-glass/epoxy at 5600N fatigue strength factor is 1

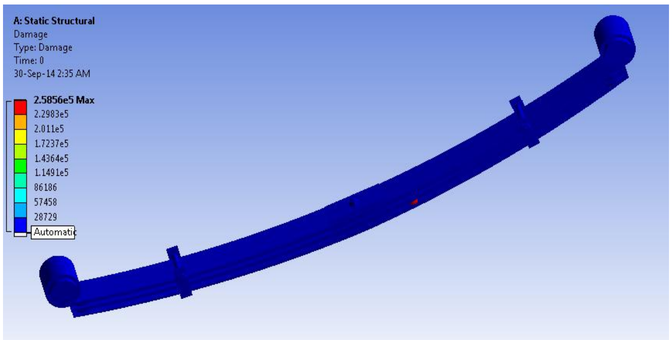


Fig.4.4 shows fatigue damage of carbon/epoxy at 5600N fatigue strength factor is 1

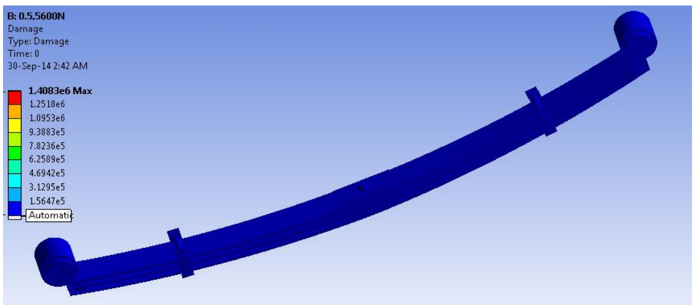


Fig.4.5 shows fatigue damage of carbon/epoxy at 5600N fatigue strength is 0.5

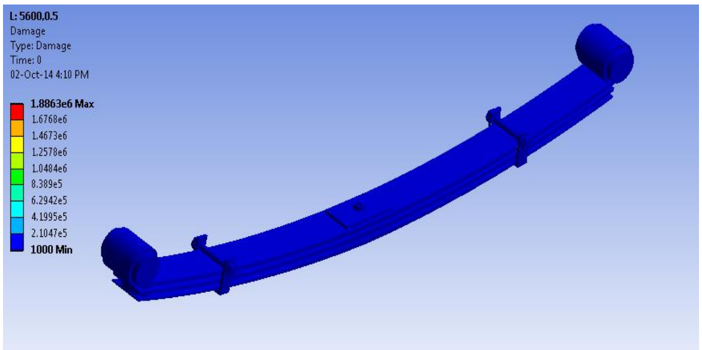


Fig.4.6 shows fatigue damage of kevlar/epoxy at 5600N fatigue strength factor is 0.5

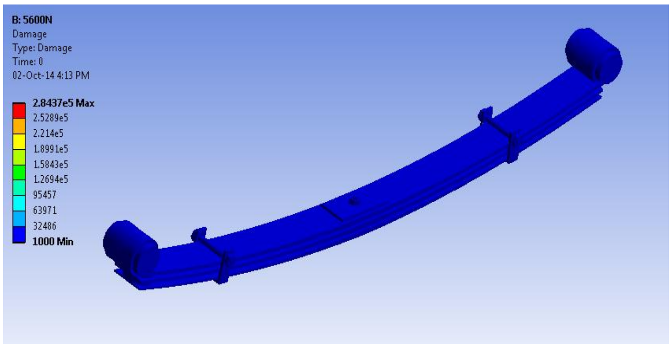


Fig.4.7 shows fatigue damage of kevlar/epoxy at 5600N fatigue strength factor is 1

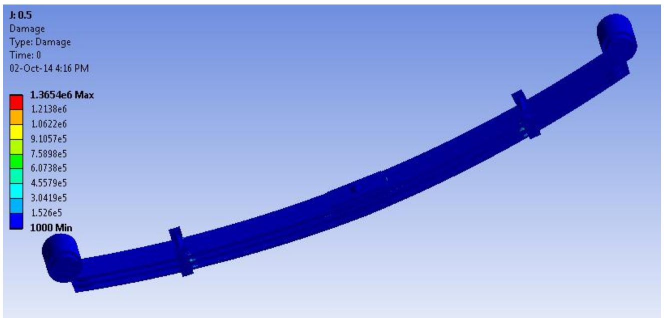


Fig.4.8 shows fatigue damage of steelEN45 at 5600N fatigue strength factor is 0.5

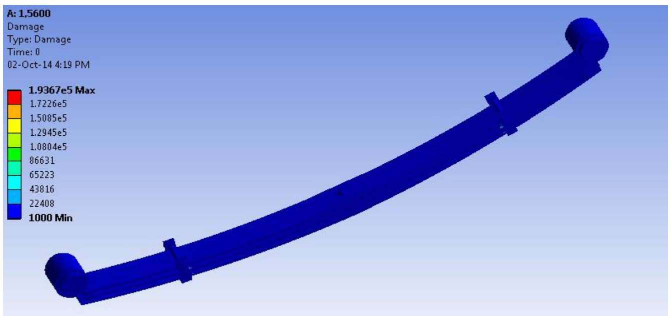


Fig.4.9 shows fatigue damage of steelEN45 at 5600N fatigue strength factor is 1

4.3 Fatigue safety factor

Fatigue Safety Factor is a contour plot of the factor of safety with respect to a fatigue failure at a given design life. The maximum Factor of Safety displayed is 15 like damage and life. Safety factor is a term that describes the structure capacity of a system beyond the expected loads and actual loads. The safety factor test is also performed using ANSYS-14, for fatigue strength factor of 0.5 to 1. The results shows that the safety factor of the parabolic leaf spring made up of E-glass/epoxy, carbon/epoxy, Kevlar/epoxy, steel EN45 is more than one and this value indicated that the parabolic leaf spring is safe as the value is less than one indicate failure before design life is reached.The results are shown below obtained when fatigue strength factor 0.5 and 1.

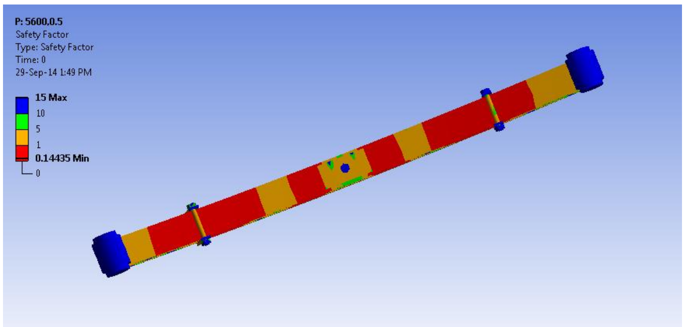


Fig.4.10 shows fatigue SF of e-glass/epoxy at 5600N fatigue strength is 0.5

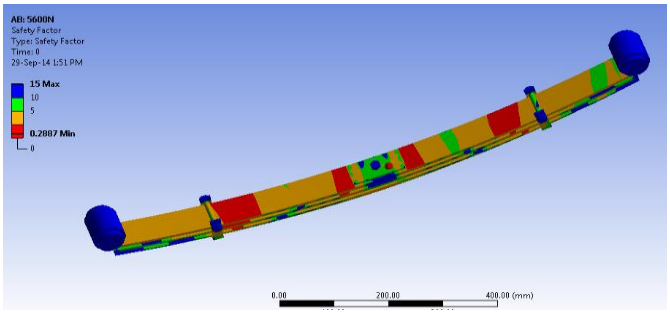


Fig.4.11 shows fatigue SF of e-glass/epoxy at 5600N fatigue strength is 1

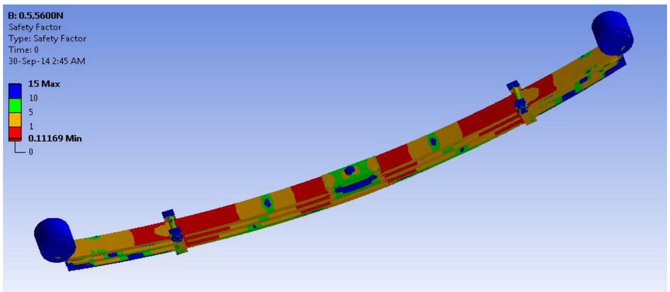


Fig.4.12 shows fatigue SF of carbon/epoxy at 5600N fatigue strength is 0.5

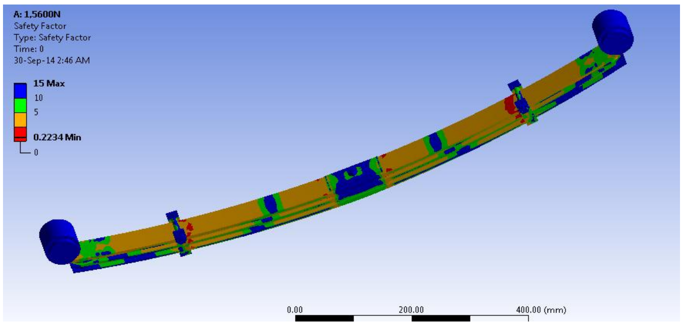


Fig.4.13 shows fatigue SF of carbon/epoxy at 5600N fatigue strength is 1

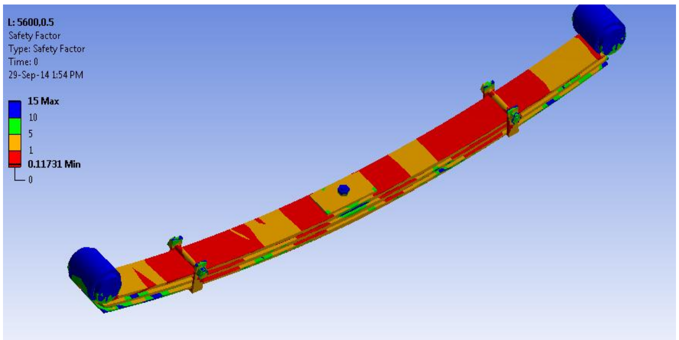


Fig.4.14 shows fatigue SF of kevlar/epoxy at 5600N fatigue strength is 0.5

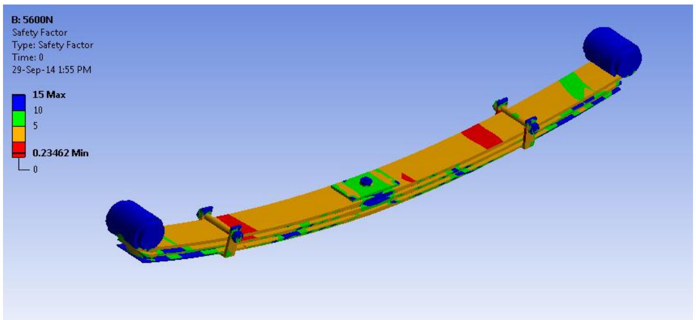


Fig.4.15 shows fatigue SF of kevlar/epoxy at 5600N fatigue strength is 1

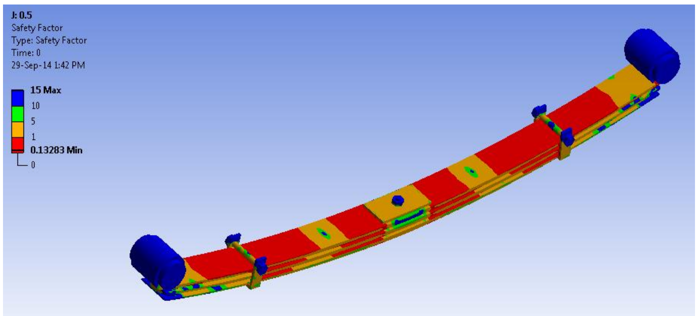


Fig.4.16 shows fatigue SF of steelEN45 at 5600N fatigue strength is 0.5

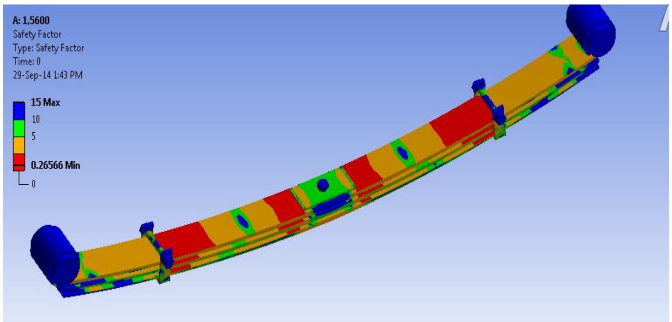


Fig.4.17 shows fatigue SF of steel EN45 at 5600N fatigue strength is 1

4.4 Fatigue sensitivity

Fatigue Sensitivity shows a function of the loading vs available life at the critical location on the parabolic leaf spring model

This result could also be scoped. Sensitivity could also be found for life, damage, or factor of safety. The user may set the amount of fill points as well as the load variation limits. for instance , the user might need to see the sensitivity of the model's life if the FE load was 50% of the current load up to if the load 150% of the current load. a worth of 100% corresponds to the life at the current loading on the model. Negative variations are allowed so as to see the effects of a possible negative mean stress if the loading is not totally reversed. Linear, Log-X, Log-Y, or Log-Log scaling are often chosen for chart display. Default values for the sensitivity options could also be set through the Control Panel.

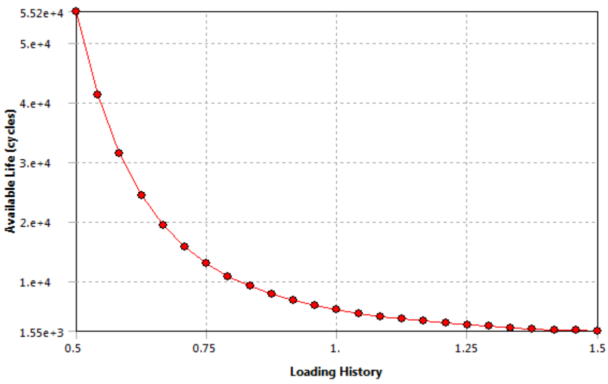


Fig- 4.18 shows the variation of life cycle e-glass/epoxy at 5600N and strength factor is 1

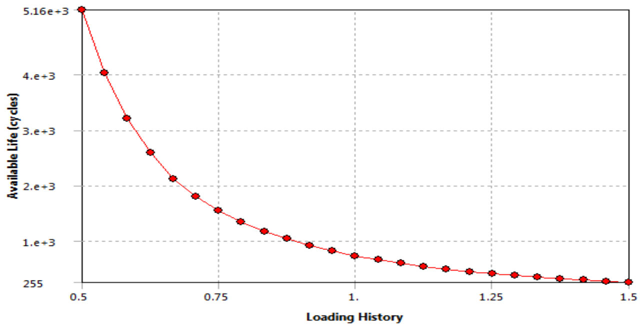


Fig-4.19 shows the variation of life cycle e-glass/epoxy at 5600N and strength factor is 0.5

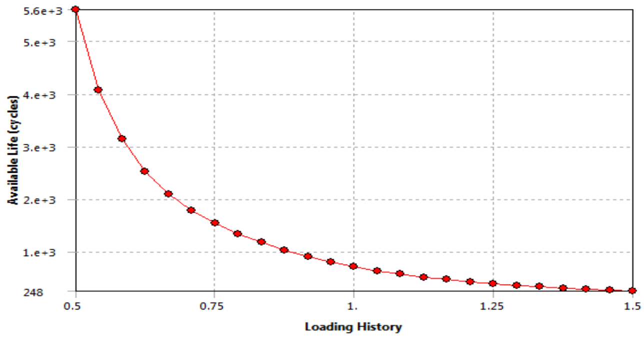


Fig- 4.20 shows the variation of life cycle carbon/epoxy at 5600N and strength factor is 0.5

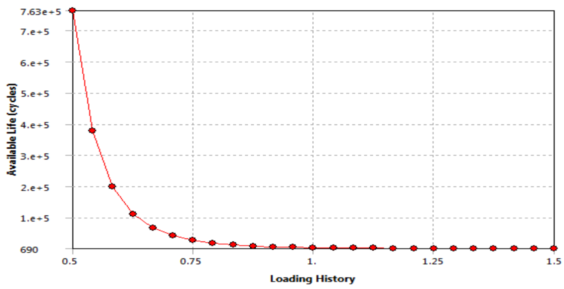


Fig- 4.21 shows the variation of life cycle carbon/epoxy at 5600N and strength factor is 1

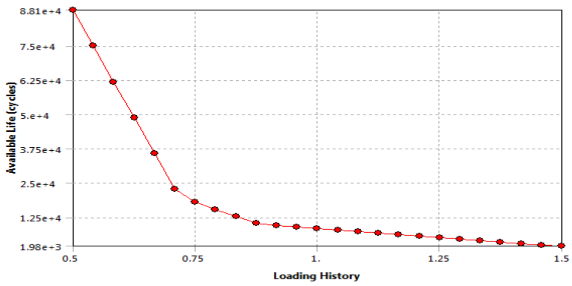


Fig- 4.22 shows the variation of life cycle kevlar/epoxy at 5600N and strength factor is 0.5

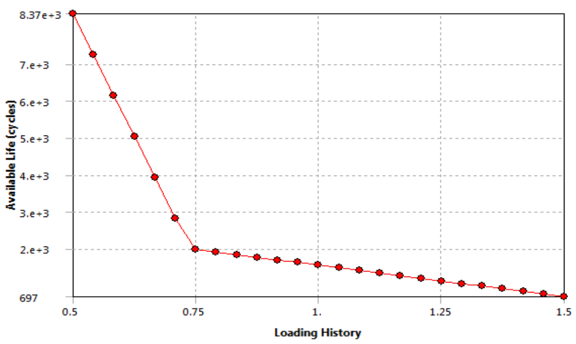


Fig- 4.23 shows the variation of life cycle kevlar/epoxy at 5600N and strength factor is 1

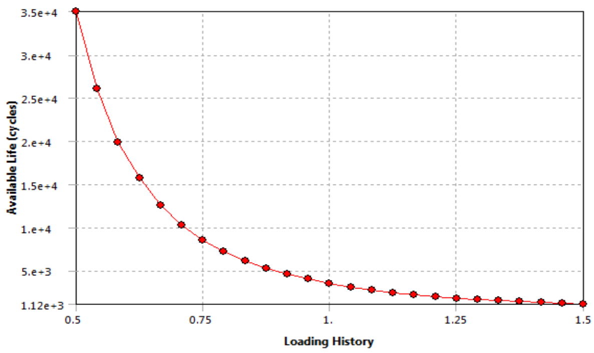


Fig-4.24 shows the variation of life cycle steelEN45 at 5600N and strength factor is 0.5

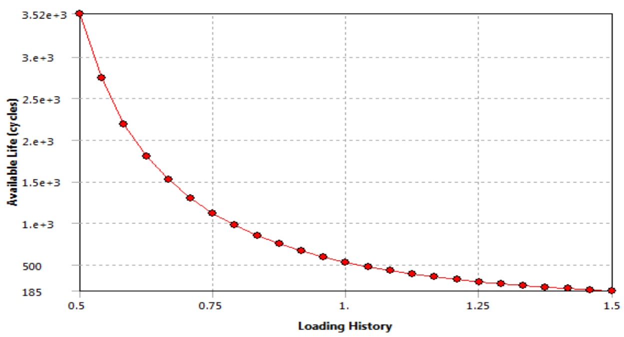


Fig-4.25shows the variation of life cycle e-glass/epoxy at 5600N and strength factor is 1

5 conclusion and future scope

5.1 Conclusion

Fatigue analysis analyzed using Fatigue Tool predicting CAE results in terms of Fatigue life, Fatigue Sensitivity, Fatigue Damage, and Fatigue Safety factor. Using the constant amplitude loading and stress life approach, the fatigue damage and life of the spring have been predicted. From the damage contour, the highest damage value is an acceptable range. The fatigue analysis of the parabolic leaf springs is carried with four approaches, Gerber and Goodman's approach is found out to give better results for the analysis of life data for parabolic leaf springs. According to the total life approach, the fatigue life of E - Glass Epoxy composite parabolic leaf spring is higher than that of steel EN45 parabolic leaf spring. This study will help to understand the behavior of the parabolic leaf spring and give information for the manufacturer to improve the fatigue life of the leaf spring using CAE tools. It can help to reduce costs and time in the research and development of the new product. Finite element method using CAE tool like ANSYS-14 Workbench prove the reliability of the validation methods based only on simulation, thereby saving time, This work will help to understand linear static behavior of the composite parabolic leaf spring and simulation data for the researchers to improve the fatigue life of the parabolic leaf spring using Computer Aided Engineering tool.

5.2 SCOPE OF FUTURE WORK

After carrying out the present research work, it is found that the following things can be added as an extension to this work-

1. As analysis of composite parabolic leaf spring and steel EN45 parabolic leaf spring is validated by the analytical results, so one can validate with the manufacturing of actual prototype of composite and steel EN45 parabolic leaf spring by testing on the universal testing machine(UTM).

2. As this analysis is under static load conditions, so one can go for the analysis of composite and steel EN45 parabolic leaf springs under dynamic loading conditions.

3. Vibration analysis of parabolic leaf springs.

4. Experimental procedure is also used for performing and obtaining good results.

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