Fatigue Stress Analysis of Composite Material Leaf Spring

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ABSTRACT
The finite element (FE) modeling and analysis of a multi-leaf spring has been carried out. It includes two full-length leaves in which one is with eyed ends and seven graduated length leaves. Different types of material have been chosen like steel, aluminum, carbon epoxy and glass epoxy. The model of the leaf spring has been generated in Pro/e5.0 and imported in ANSYS-12 for FE analysis, which are the most popular CAE tools. The FE analysis of the leaf spring has been performed by discretization of the model in infinite nodes and elements and refining them under defined boundary condition. Bending stress and deflection are the target results. A comparison of different material results has been done to conclude the low-weight optimum model.

Keywords: *CAE tools, composite materials, fatigue, FEM, finite element analysis, leaf spring, stress analysis*

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INTRODUCTION

Leaf springs, also referred to as semi-elliptical springs or cart springs, are one of the oldest forms of suspension used in vehicles, especially heavy vehicles. A leaf spring looks similar to a bow minus the string. It consists of a stack of curved narrow plates of equal width and varied length clamped together with shorter plates at the centre to form a semi-elliptical shape. The center of the arc provides location for the axle, tie holes are provided at either end for attaching to the body. There are different varieties of leaf springs, namely mono-leaf springs and multi-leaf springs. As the name suggests, the mono-leaf suspension consists of a single link. They are thick in the middle and taper out at the end. It doesn't offer much strength and suspension to towed vehicles. Multi-leaf springs are used for heavier vehicles which offer increased strength and suspension. A more modern design is the parabolic leaf spring. It can have a mono-leaf or multi-leaf configuration. It has fewer leaves in comparison to the semi-elliptical multi-leaf springs whose thickness varies from centre to the end and it follows a parabolic path. This configuration not only saves weight but also gives greater flexibility which improves ride quality. A trade-off of using parabolic leaf spring is reduced load-carrying capability (Figure 1).[1-2]

LEAF SPRINGS AND MATERIALS USED

The leaf spring should absorb the vertical vibrations and impacts due to road irregularities by means of variations in the spring deflection so that the potential energy is stored in spring as strain energy and then released slowly. So, increasing the energy storage capability of a leaf spring ensures a more compliant suspension system. According to the studies, a material with maximum strength and minimum modulus of elasticity in the longitudinal direction is the most suitable material for a leaf spring (Figure 2 and Table 1).

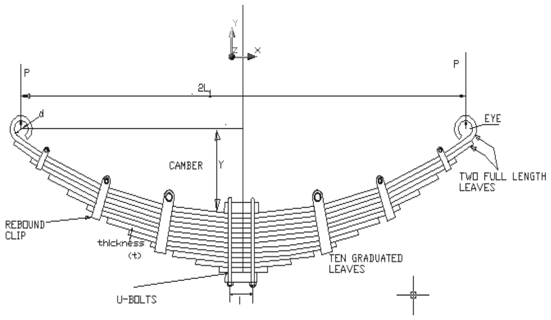

Fig. 1. *Elliptical spring.*

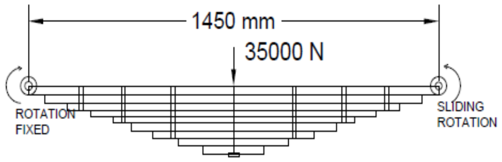

Fig. 2. *Flat spring.*

Table 1. *Material properties.*

Parameter	Steel	Al	e-Glass epoxy	Carbon epoxy
E-X (Pa)	2e11	7e10	50e9	1.34e11
E-Y (Pa)	–	–	12e9	7e9
E-Z (Pa)	–	–	12e9	7e9
P-XY	0.266	0.3	0.3	0.3
P-YZ	–	–	0.3	0.3
P-ZX	–	–	0.3	0.3
G-XY (Pa)	–	–	5.6e9	5.8e9
G-YZ (Pa)	–	–	5.6e9	5.8e9
G-ZX (Pa)	–	–	5.6e9	5.8e9
ρ (kg/m^3)	7860	2470	2000	1600

NUMERICAL EXAMPLE

The three-dimensional model of the multi-leaf spring is shown in the figure 3. The multi-leaf spring has modeled maximum deflection, i.e. flat position reverse direction to attain its original shape, i.e. semi-elliptical. The boundary condition is the collection of different forces, pressure, velocity, supports and constraints required for complete analysis. As per the specifications, the spring is drawn at flat condition; therefore, the load is applied in downward direction to achieve initial no-load condition. As no-load camber is 153°, a joint rotation of 27° is considered for both revolute joints, during static analysis. The boundary conditions for the experimental results are shown in Figures 4–10.

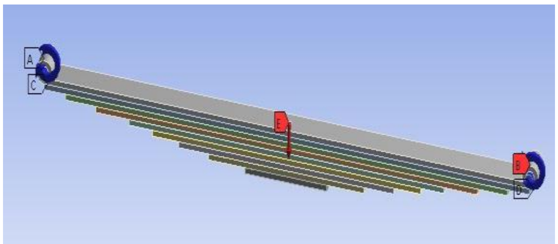

Fig. 3. *Modeling and finite element analysis.*

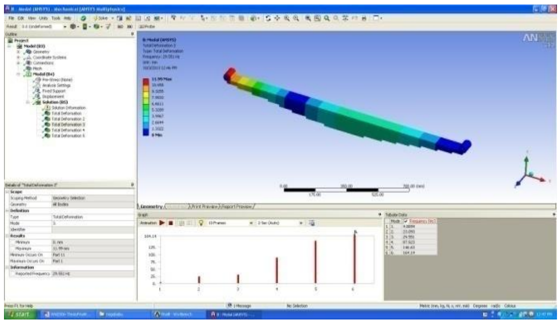

Fig. 4. *Natural frequencies for steel.*

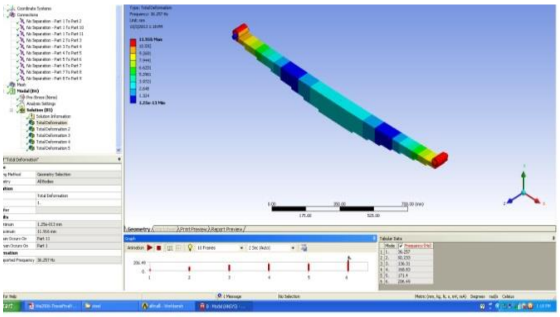

Fig. 5. *Natural frequencies for aluminum.*

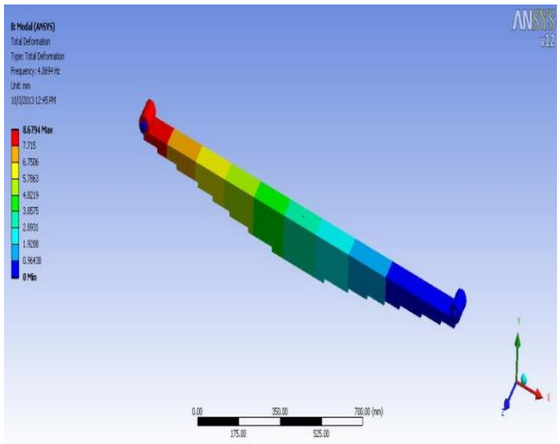

Fig. 6. *First-mode shape of steel leaf.*

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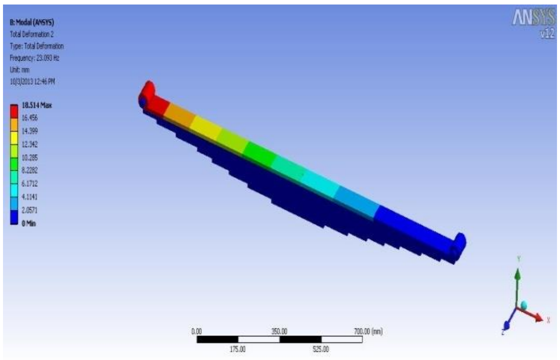

Fig. 7. *Second-mode shape of steel leaf.*

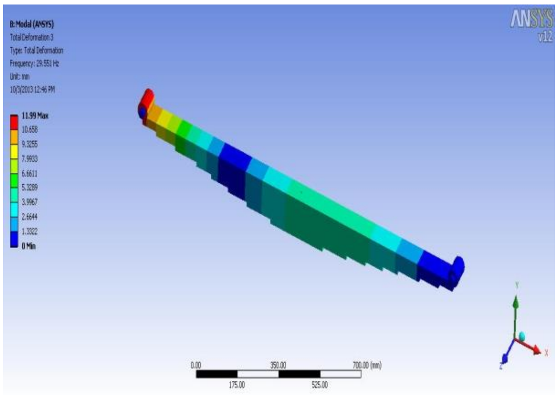

Fig. 8. *Third-mode shape of steel leaf.*

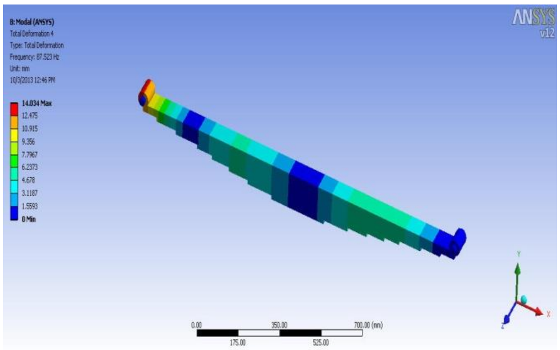

Fig. 9. *Fourth-mode shape of steel leaf.*

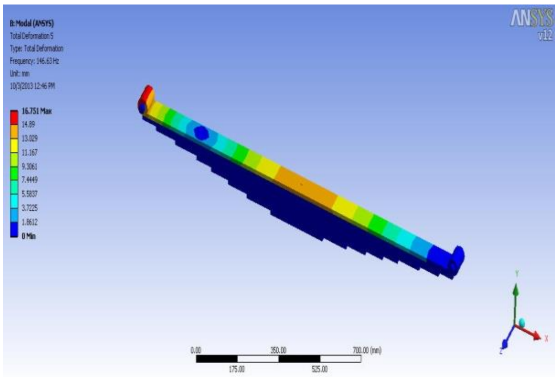

Fig. 10. *Fifth-mode shape of steel leaf graph for all frequencies of steel leaf.*

RESULTS AND DISCUSSION

In this present work, static, modal and harmonic analyses are performed in steel, aluminum, glass epoxy and carbon epoxy materials [3-4]. Considering the same boundary condition and loading, static analysis results are shown in Table 2.

Table 2. *Static analysis results.*

Parameter	Steel	Al	e-Glass	Carbon epoxy
Deformation (mm)	66	189	713	233
Bending stress (MPa)	618	618	856	920

Modal analysis [5-6] is used for finding the natural frequencies of total spring; it is totally depending up on weight and shape of spring due to which we can find out where the resonance will occur.

Modal analysis natural frequencies are shown in Table 3.

Table 3. *Modal analysis natural frequencies.*

Mode no.	Steel (Hz)	Al (Hz)	e-Glass (Hz)	Carbon epoxy (Hz)
1	0.992	1.062	1.921	1.019
2	3.307	3.538	1.928	2.688
3	3.31	3.542	2.01	3.604
4	3.37	3.61	2.398	3.886

CONCLUSION

The total individual leaf length and number of leafs are designed theoretically and the total deformation and bending stresses are obtained as per design calculations. Using different lengths, each leaf is modeled in PRO/E modeling software and assembled as a single product, and analysis is performed by considering boundary conditions like fixed joint, revolve joint and sliding in *x*-directions. Loading 35,000 N was taken into consideration at the center of the entire leaf spring. After post-processing, design results and ANSYS analysis results are compared for steel and aluminum.

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