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Finite Element Analysis of Composite Leaf Spring under Static and Fatigue Loads

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Abstract

Presently researchers have been trying to reduce the weight of automobiles especially components like leaf springs. The present research paper represents the general study, fabrication and finite element analysis of metal matrix composite (MMC) leaf spring. A possibility of metal matrix composite leaf spring was investigated to replace the steel spring. EN 45 steel rear leaf spring of commercial vehicle was selected for the study. Stir casting technique was used to make metal matrix composite (MMC) leaf spring of Al-B_4C. Finite element based software ANSYS 14.0 was used to analyze the deflection, stress and fatigue strength of steel leaf spring and composite leaf spring. Results showed that although deflection of composite leaf spring is more than steel spring and fatigue strength of composite leaf spring is more than the desired 100000 cycles.

Keywords: *Composite Leaf Spring; Steel Leaf Spring; Finite Element Analysis; Fatigue Analysis; Static Analysis.*

1. Introduction

Aluminum, magnesium, boron carbide, silicon carbide, titanium and alumina are mostly used to manufacture metal matrix composite component. When more than two materials are used to manufacture composite material that material is known as hybrid composite material. The most widely use methods for the manufacture of metal matrix composite materials and composite parts are stir casting, centrifugal casting, squeeze casting and powder metallurgy. Metal matrix composite are used in automobile industry to manufacture interior, exterior, chassis and power transmission components. Due to increase in demand for better fuel efficient vehicles, light weight components and parts consolidation are the major issues for increase in the demand of metal matrix based components in the automobile industry. Metal matrix composite’s provide design flexibility which push the automobile market towards composite based components. New innovations, experiments and numerical analysis may help to develop new automobile component based on metal matrix composite material. Leaf springs are one of the oldest suspension components and they are still frequently used in commercial vehicles. The automobile industries have shown interest in replacement of steel springs with composite leaf springs due to high strength to weight ratio. Reducing weight while increasing or maintaining strength of products is getting to be most important research issue.

The automobile industry also has showed a great interest in the replacement of steel springs by fiber glass reinforced composite leaf springs. A single leaf spring of variable thickness of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to the multilayer steel spring was designed (Pardeep R, Vikram CJ & Naveenchandran P, 2012). Steel leaf spring used in the rear suspension system of light vehicles was analyzed using ANSYS V5.4 software. Stress and deflection verified the existing analytical and experimental solutions. Using the results of the steel leaf spring, a composite one spring made from fiberglass with epoxy resin was designed and optimized using ANSYS. A spring with minimum weight obtain that was capable of carrying given static external forces without failure (Shokreih MM & Rezeai D, 2003). Comparative analysis of Carbon/epoxy composite leaf spring and steel leaf spring was done by analytical and finite element analysis using ANSYS 12.0. Compared to mono steel leaf spring the laminated composite mono leaf spring was found lesser stresses and weight reduction of 22.15% was achieved (Ravindra P & Belkar S, 2014). The finite element method (FEM) was performed on the spring model to observe the distribution of stress and damage, when using the loading sequences was predominantly tensile in the nature and the life of mounting in Goodman approach is more conservative (Karthik JP, Chaitanya KL & Sasanka CT, 2012). Leaf springs are suspension components and are used especially in commercial vehicles. Modeling and analysis of composite mono leaf spring (GFRP) compared with steel spring by using ANSYS 10.0 software (Patunkar MM & Dolas DR, 2011). Nano particles effectively enhance the mechanical properties in the metal matrix composite than micron level particles because of its bonding nature. Investigation of fatigue life of the produced MMNCs were investigated by advanced rotating beam fatigue testing machine to understand the impacts of reinforced nano particles (Divagar S, Vignashwar M & Selvamani ST, 2016). Static and fatigue analysis of steel leaf spring and composite multi leaf spring made up of glass fiber reinforced polymer were analyzed using life data analysis. Fatigue life of composite was more than that of conventional steel leaf spring (Mouleeswaran S & Vijayaragan S, 2007).

The latest research in automobile industries shows that most of the researchers work on composite material to manufacture automobile components like piston, brake drum, connecting rod and valve stem. From literature it has been seen that most of the research was carried out on mechanical properties, shape optimization and failure behavior by experimental and finite element approach on composite leaf springs made of E-Glass/Epoxy and Carbon/Epoxy material. The present study attempts to investigate the possibility to manufacture metal matrix composite leaf spring and to perform finite element analysis of steel leaf spring and composite leaf spring under static and fatigue analysis. EN45 steel rear leaf spring of commercial vehicle has considered as experimental application. Leaf spring with aluminum and boron carbide based composite was manufactured by stir casting technique. Fatigue life and deformation under different loading conditions of metal matrix composite leaf spring are performed as per the standards - IS 1135: 1995 (Leaf Springs assembly for automobiles) and SAE HS - J788 (Manual on Design and Application of Laminated Springs, 1990).

2. Materials and Methods

Finite element based software ANSYS 14.0 was used step by step for static and fatigue analysis of steel leaf spring and composite leaf spring. The objective of this analysis is to find out the deflection of steel spring and composite leaf spring under given load and compare the result of steel spring and composite leaf spring. Finite element software was also used to find out fatigue life of steel leaf spring and composite spring steel under fatigue loads. The comparison of result of composite leaf spring with steel leaf spring gave validation for use of composite leaf spring in place of traditional steel leaf spring.

3. Results and Discussion

Finite element analysis results for static and fatigue analysis are presented in this section:

3.1 Static Analysis

The rear steel spring of Tata ace (mini truck) has been considered as practical application for this study. The dimension of steel spring of material EN45 are the length 915mm, width 57mm and thickness 7mm. The geometrical modeling of steel spring was prepared in Solidworks software. The properties of EN45 material are given in Table 1.

Table 1: Mechanical Properties of EN45

Material	Young's Modulus, E (N/mm^2)	Poisons Ratio	Tensile Strength (MPa)	Density (kg/m^3)
EN45	207000	0.266	621	7850

After preparation of geometrical model and application of material properties, the geometrical model of steel spring was meshed into small elements. Meshing helps to divide the whole leaf spring into small elements. The minimum element size of 5mm was considered for mesh generation as leaf spring contains sharp edges and curves. For the boundary condition, it is assumed that both ends of leaf spring are designed as eye shapes so that both ends are connected to the frame of the vehicle and a simple pin is used to connect leaf spring to the frame of body but it is restricted to translate and rotate in all other directions. So under the static analysis of steel spring, boundary conditions are apply as mention above, spring is allowed to move only in x-direction when load is applied and all other sides are restricted to move. The load is applied at the centre of the steel spring and deflections are induced in steel spring. The Initial load applied on the spring was 1000N and after that 2000N, 3000N, 4000N, 5000N and full load of 5400N was applied on the spring to find the deflection. The deflection under full load of 5400 N during finite element analysis is shown in Fig. 1. The results of deflection under different loads are tabulated in Table 2.

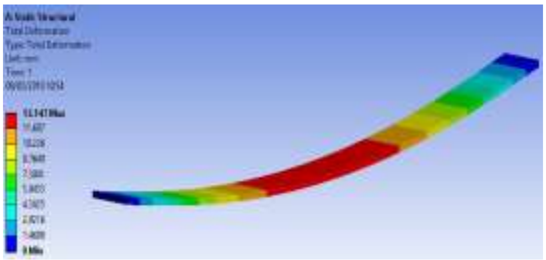

Fig. 1 Static analysis of steel leaf spring under full load i.e. 5400N

Table 2: Deflection in steel spring under different loads

Load Applied in N	Deflection in Steel Spring (mm)
1000	7.1
2000	9.2
3000	10.69
4000	11.8
5000	12.8
5400	13.14

For the static analysis of composite leaf spring, first of all composite leaf spring was manufactured by stir casting process. Aluminum of grade 7075-T651 was used as base material and 25% by weight of boron carbide was used as reinforcement in base material. When aluminum temperature reached 850°C in electric furnace than boron carbide was added to the crucible in very control manner. The mixture of aluminum and boron carbide was stirred with the help of the stir casting machine at 400 rpm for about 10 minutes in order to ensure homogeneous mixture of the materials. When the materials get properly mixed, the molten mixture of aluminum 7075 and boron carbide was poured to the prepared mould of the leaf spring. After solidification composite leaf spring removed from the mould. To find the deflection of composite leaf spring by finite element method same procedure was adopt as used in the steel spring. The deflection in the composite leaf spring is shown in Fig. 2. The result of deflection by finite element method of composite spring under different loads is shown in Table 3.

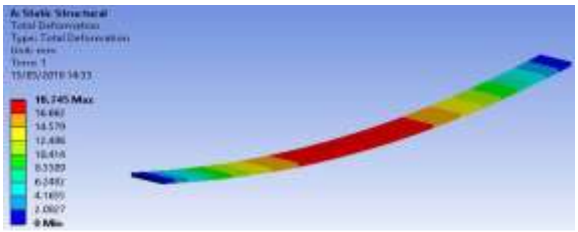

Fig. 2 Static analysis of composite leaf spring under full load i.e. 5400N

Table 3: Deflection in composite spring under different loads

Load Applied in N	Deflection in Composite Spring (mm)
1000	10.45
2000	13.37
3000	15.38
4000	16.69
5000	18.26
5400	18.75

Comparison of deflection results of steel leaf spring and composite leaf spring show that composite leaf spring has more deflection than steel leaf spring. Comparison of both springs is shown in Fig. 3.

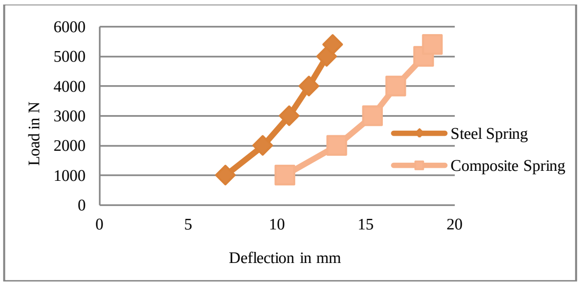

Fig. 3 Load deflection curve for steel and composite leaf spring

3.2 Fatigue Analysis

Initially leaf spring is good in service but after long service period may fail due to repeated load on the spring. Fatigue analysis is carried out to find out the material capacity to withstand with the number of cycle without failure during its service time. After static analysis, fatigue analysis is performed also by ANSYS to find the fatigue strength of steel leaf spring and composite leaf spring. For the fatigue analysis of both springs, the same geometry is used as used in the static test analysis. During fatigue analysis the range of cyclic load applied is from 1000N to 5400N on spring and result of stress and fatigue life has obtained as shown in the Table 4.

Table 4: Stress in leaf springs during fatigue test

Load Applied (N)	Stress in Steel Spring (MPa)	Stress in Composite Spring (MPa)	Fatigue Life (Cycles)
1000	85.9	51.75	100000
2000	122.40	74.20	100000
3000	150.50	91.02	100000
4000	174.58	107.30	100000
5000	195.98	120.91	100000
5400	204.01	126.11	100000

It was found from the analysis that steel spring and composite leaf spring has fatigue life of more than 100000 cycles. Fatigue analysis performed on both spring under full load 5400 N as shown in Fig. 4 and Fig. 5.

Fig. 4 Fatigue analysis of steel leaf spring under full load i.e. 5400N

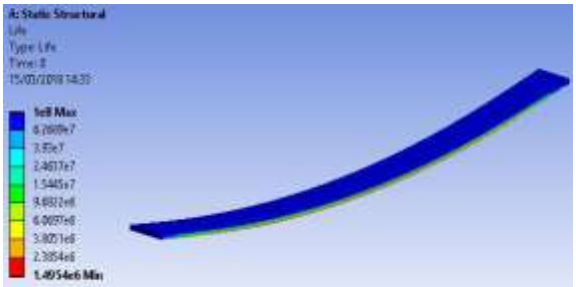

Fig. 5 Fatigue analysis of composite leaf spring under full load i.e. 5400N

During fatigue analysis, the composite leaf spring shows less stress as compared to the steel leaf spring as shown in Fig. 6.

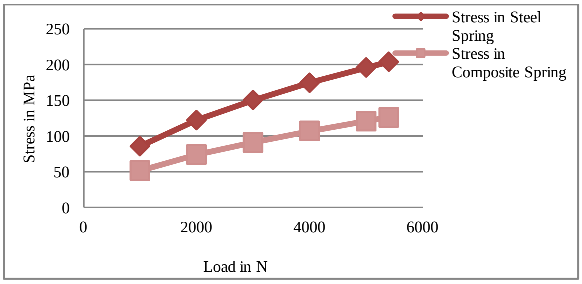

Fig. 6 Stress produced in leaf springs during fatigue analysis

4. Conclusions

Metal matrix based composite leaf spring was successfully manufactured by stir casting method. Finite element analysis of metal matrix composite based leaf spring and steel spring was successfully performed under static and fatigue loads. The small difference in deflection results was obtained during the static load condition in which composite leaf spring deflected more than steel spring. When finite element analysis was carried out, the composite leaf spring produces less stress as compared to the steel leaf spring in static loading test. Fatigue life cycle of steel leaf spring and composite leaf spring has obtained infinite life and more than the design value 100000 cycles. So, composite leaf spring can replace steel leaf spring with advantage of reduced weight of an automobile.

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