A Comparative Study of Standard, Casted and Riveted Eye Design of a Mono Leaf Spring Using CAE Tools

Gian Bhushan, Vinkel Arora, M.L. Aggarwal

Abstract**—**The objective of the present study is to determine better eye end design of a mono leaf spring used in light motor vehicle. A conventional 65Si7 spring steel leaf spring model with standard eye, casted and riveted eye end are considered. The CAD model of the leaf springs is prepared in CATIA and analyzed using ANSYS. The standard eye, casted and riveted eye leaf springs are subjected to similar loading conditions. The CAE analysis of the leaf spring is performed for various parameters like deflection and Von-Mises stress. Mass reduction of 62.9% is achieved in case of riveted eye mono leaf spring as compared to standard eye mono leaf spring for the same loading conditions.

Keywords**—**CAE, Leaf Spring, 65Si7 spring steel.

I. Introduction

LEAF springs are most frequently used in the suspensions. Leaf springs like all other springs serve to absorb, store and releases energy. In light passenger vehicles a mono leaf is used or mono leaf with helper spring is used. It provides dampness and springing function. It is attached directly to the frame at the both ends or attached directly to one end usually at the front with the other end attached through a shackle, a short swinging arm. During its operation, the main leaf (with eyes) is under the action of longitudinal and lateral forces, therefore it is not desired that the maximum stress is induced in it. The stress induced in the leaf spring can be reduced by proper eye design [1], [2]. An eye end plays a vital role during application of leaf spring but eyes have the critical areas where the stresses induced are high. In this work single leaf spring is modeled using dedicated modeling software CATIA and considering various eye designs the stresses induced in a leaf spring are computed. The different types of the eye designs considered are: standard eye, casted eye and riveted eye. Fig. 1 depicts the standard eye which is widely used in actual practice for light weight passenger cars because of its simpler design and manufacturing process. In casted eye (Fig. 2), the eye end and spring are manufactured simultaneously from the same material by continuous casting. There is no stress concentration in this type of eye design. This joint configuration has the disadvantages of high cost and manufacturing complexity. Fig. 3 depicts a riveted eye of steel that can be bolted or pinned to the fibre glass epoxy resin (FGER) body of the spring. Although riveted or bolted eye ends are fairly simple to manufacture for prototypes, they are not normally recommended for volume production. That is because fasteners are relatively expensive to produce and assemble. Stress concentrations introduced by drilling are another concern for this type of joint.

Gian Bhushan is with the National Institute of Technology, Kurukshetra, Haryana, India 136119 (phone: +91 1744 233463; fax: +91 1744 238050; e-mail: aroragian@yahoo.com).
Vinkel Arora is with National Institute of Food Technology Entrepreneurship and Management, Sonipat, Haryana, india (e-mail: vinkelarora@gmail.com).
M. L. Aggarwal is with the YMCA University of Science and Technology, Faridabad, Haryana, India (e-mail: aggarwalmlal@rediffmail.com).

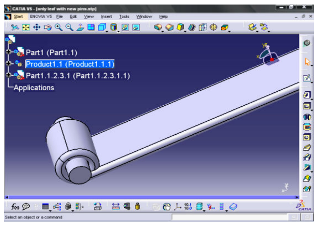

Fig. 1 Standard eye

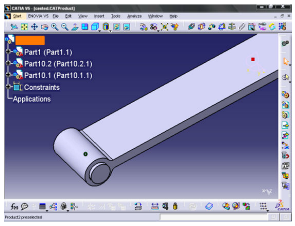

Fig. 2 Casted eye

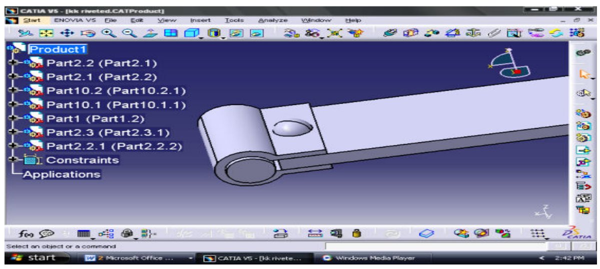

Fig. 3 Riveted eye

Mouleeswaran et al. [3] performed static and fatigue analysis of steel leaf springs and composite multi leaf spring made up of glass fiber reinforced polymer using life data analysis. The dimensions of existing conventional steel leaf springs of a light commercial vehicle were taken and verified by design calculations. Static analysis of 2-D model of conventional leaf spring was also performed using ANSYS 7.1 and compared with experimental results. A. Al-Qureshi [4] designed, fabricated and tested a single leaf, variable thickness spring of glass fiber reinforced plastic (GFRP) with similar mechanical and geometrical properties to that of a multi leaf steel spring. Leaf springs industries working with 65Si7 spring steel are using a very low factor of safety for weight reduction. Gulur Siddaramanna [5] suggested replacement of spring steel with fiberglass composite leaf spring because of its high strength to weight ratio. Rajendran et al. [6] formulated a solution technique using genetic algorithms (GA) for design optimization of composite leaf springs. Patunkar et al. [7] worked on non-linear force displacement of each leaf spring as well as the spring characteristics of a pack consist of two to four leaves using ANSYS. The results from ANSYS were compared with those from the test, which showed a fairly good agreement with each other. Chantranuwathana et al. [8] simulated a leaf springs model. An experimental leaf springs model was verified by using a leaf springs test rig that could measure vertical static deflection of leaf springs under static loading condition. The results showed a non-linear relationship between the applied load and the leaf springs deflection for both directions of loading, in form of a hysteresis loop. Peiyong Qin [9] used abacus for the design and analysis of a leaf spring. Vinkel et al. [10] and Krishan et al. [11] described the CAE solution for static analysis of the leaf springs and compared CAE results with experimental results. In CAE analysis, the load was applied at the centre and eyes and pins were the fixed supports. There was a good correlation between experimental and CAE results validating CAE model.

The objective of the present work is to determine the better eye design which can lower the stress induced in the mono leaf spring. A 65Si7 lightweight passenger car leaf spring is considered for this study. The standard, casted and riveted eye designs of mono leaf spring are compared using CAE tools. The CAD models of the standard, casted and riveted eye design have been prepared in CATIA and analyzed using ANSYS. For standard and casted eyes, the material used is 65Si7 while for riveted eye the spring strip is of FGER and the eye is of 65Si7. The similar types of loading conditions are applied on each leaf spring and the results are compared. The better eye design among standard, casted and riveted has been suggested.

TABLE I
PROPERTIES OF 65SI7

Parameter	E	HRC	ν	Mass density	Tensile Yield strength	Tensile Ultimate strength
Value	2.1×10^5 N/mm^2	38	0.266	0.00000785 kg/mm^3	1158 MPa	1272

II. MATERIALS AND DESIGN PARAMETERS

A. Material for Standard and Casted Eye Leaf Springs

The basic requirement of leaf springs steel is that the selected grade of steel must have sufficient harden ability for the size involved to ensure a full martenstic structure throughout the entire leaf section. In general terms higher alloy content is mandatory to ensure adequate harden ability when the thick leaf sections are used. The material used is 65Si7 for the standard and casted eye leaf spring. The mechanical properties of 65Si7 are shown in Table I.

B. Material for Riveted Eye Leaf Spring

The strain energy stored in the spring plays a vital role in the designing process. The relationship of the specific strain energy can be expressed as:

$$U = \frac{\sigma^2}{\rho E}$$

where σ is maximum allowable stress induced in the spring, ρ is density and E is Young's modulus of elasticity.

It can be observed that material having lower modulus and density will have a greater specific strain energy capacity. The introduction of composite materials has made it possible to reduce the weight of the leaf spring without any reduction of load carrying capacity and stiffness as the composite materials have more elastic strain energy storage capacity and high strength-to-weight ratio as compared to steel. The composite spring has much lower stresses and the spring weight is nearly 85% lower with bonded eye joints. Glass fibers consist of two major types E and S2. Although S2 fibers have better mechanical properties than E fibers, but the cost of E fibers is much lower than S2 fibers. So in the present work the E-glass/epoxy is selected as the spring material. Mechanical properties of this material are listed in Table II. This material was assumed to be linearly elastic and orthotropic.

TABLE II
PROPERTIES OF FGER

Parameter	Value	Parameter	Value
E_{xx} (MPa)	27700	G_{xy} (MPa)	2433
E_{yy} (MPa)	8400	G_{yz} (MPa)	1698
E_{zz} (MPa)	8400	G_{zx} (MPa)	2433
ν_{xy}	0.217	Mass density (kg/mm^3)	2.6*e-6
ν_{yz}	0.366	Tensile yield stress(MPa)	900
ν_{zx}	0.217		

C. Design Parameters of Leaf Spring

The various leaf spring design parameters are shown in Table III.

TABLE III
DESIGN PARAMETERS

Parameter	Leaf span	Spring stiffness	No load camber angle
Value	1450mm	220 N/mm	18°

III. MODELING AND ANALYSIS

The layout drawing of leaf springs is shown in Fig. 4.

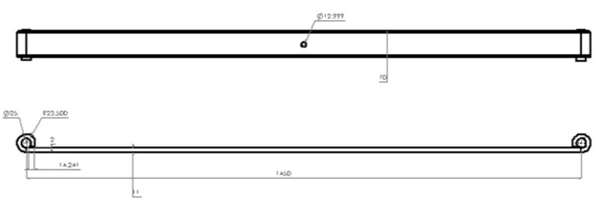

Fig. 4 Drawing of leaf spring

A. CAD Modeling

CAD modeling of any project is one of the most time consuming process. One cannot shoot directly from the form sketches to finite element model. CAD modeling is the base of any project. The finite element software will consider shapes, whatever is made in CAD model. Although most of the CAD modeling software have capabilities of analysis to some extent and most of finite element software have capabilities of generating a CAD model directly for the purpose of analysis, but their off domain capabilities are not sufficient for large and complicated models which include many typical shapes of the product. The CAD models of the eye design were prepared in CATIA and the analysis and comparison of results were performed using Ansys. The CAD model of the standard eye, casted and riveted eye are shown in the Figs. 1 to 3.

B. Analysis Using ANSYS

The CAD model of leaf springs is now imported into Ansys-11. All the boundary conditions and material properties are specified as per the standards used in the practical application. The material used for the standard and cast eye spring analysis is structural steel, which has approximately similar isotropic behavior and properties as compared to 65Si7 spring steel leaf springs. The riveted eye leaf spring material is FGER. The procedure for performing analysis in ANSYS involves:

Specifying Joints: A joint is an idealized kinematics linkage that controls the relative movement between two bodies. Joint types are characterized by their rotational and translational degrees of freedom as being fixed or free. In this assembly two revolute joints are used between eye and pin. The joint rotation is 18˚ corresponding to no load camber angle of 162º.

Meshing: Meshing is the process in which geometry is spatially discretized into elements and nodes. The mesh along with material properties is used to mathematically represent the stiffness and mass distribution of structure. The default element size is determined based on a number of factors including the overall model size, the proximity of other topologies, body curvature, and the complexity of the feature. If necessary, the fineness of the mesh is adjusted up to four times (eight times for an assembly) to achieve a successful mesh. In this assembly SOLID92 mesh element is used for the results. Fig. 5 depicts the meshing of the riveted eye mono leaf spring.

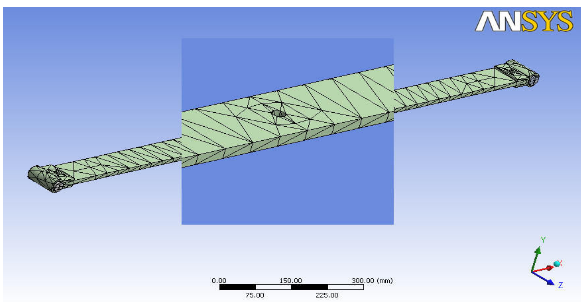

Fig. 5 Meshing of riveted eye mono leaf spring

Setting Analysis Environment: A linear static structural analysis determines the displacements, stresses, strains, and forces in structures or components caused by loads that do not induce significant inertia and damping effects. Steady loading and response conditions are assumed; that is, the loads and the structure's response are assumed to vary slowly with respect to time. Static structure analysis takes into consideration some parameters, like material properties, loading conditions, support conditions, joints and contacts which are to be specified as the input to the pre processing of the analysis.

Setting Boundary Conditions: The boundary conditions are applied by taking into consideration the experimental loading conditions. The static loading condition of single leaf spring involves the fixation of one of the revolute joint, applying displacement support at the other end of leaf springs, while applying a load at the centre of the main leaf. As per specifications the springs is drawn at flat condition, therefore the load is applied in downward direction to achieve initial no load condition. As no load assembly camber is 162°. The actual loading condition is shown in the Fig. 6 and the boundary conditions applied are shown in Fig. 7.

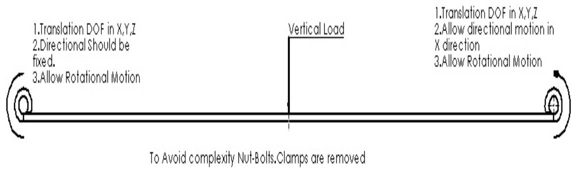

Fig. 6 Static loading conditions

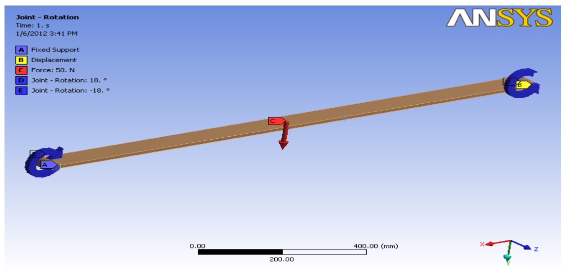

Fig. 7 Boundary conditions in Ansys

IV. Results and Discussion

A. Standard Eye

Fig. 8 depicts the total deformation plot obtained in post processing using ANSYS for a standard eye mono leaf under the application of 50N load. It is observed that the total deformation at the center is 97 mm under this load. The color contour depicts that the maximum deformation occurs at the center of the mono leaf spring, shown in red color and minimum deformation occurs at the eye end region. Fig. 9 shows the Von-Mises stress induced in the leaf spring under the application of same load. It is observed that the maximum Von-Mises stress is 690 MPa which is much below the yield stress.

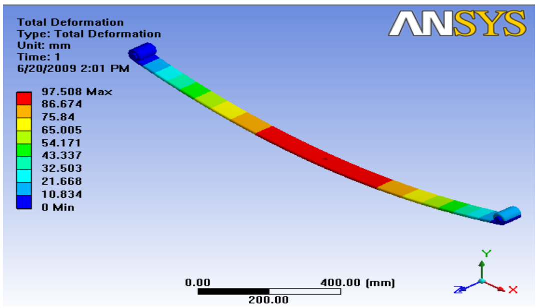

Fig. 8 Total deformation plot for standard eye

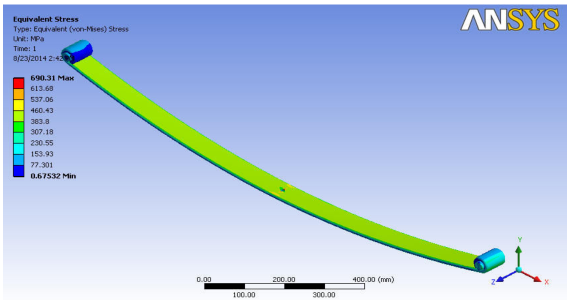

Fig. 9 Von-Mises stress plot for standard eye

B. Casted Eye

Fig. 10 shows the total deformation observed in casted eye mono leaf under the application of 50N load. It is observed that the total deformation at the center is 102 mm under this load. The color contour also depicts that the maximum deformation occurs at the center of the mono leaf spring, shown in red color and minimum deformation occurs at the eye end region. Fig. 11 shows the Von-Mises stress induced in the leaf spring under the application of same load. The maximum Von-Mises stress observed is 667 MPa which is much lower than the yield stress.

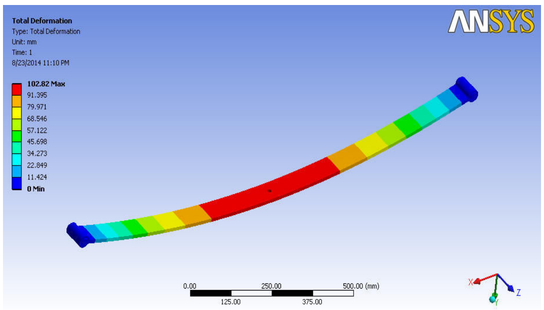

Fig. 10 Total deformation plot for casted eye

C. Riveted Eye

Fig. 12 depicts the total deformation observed in riveted eye mono leaf under the application of 50N load. It is observed that the total deformation at the center is 108.36 mm under this load. The color contour depicts that the maximum deformation occurs at the center of the mono leaf spring, shown in red color and minimum deformation occurs at the eye end region. Fig. 13 shows the Von-Mises stress induced in the leaf spring under the application of same load and it is observed from the plot that that the maximum Von-Mises stress is 778MPa which is also lower than yield stress.

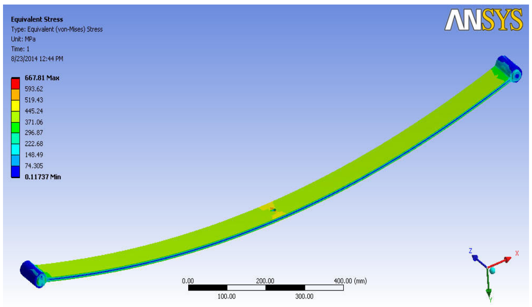

Fig. 11 Von-Mises stress plot for casted eye

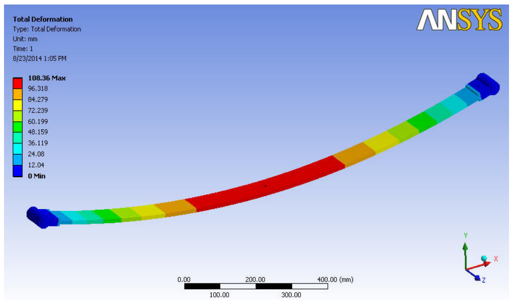

Fig. 12 Total deformation plot for riveted eye

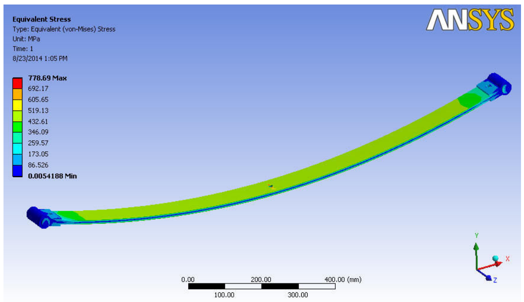

Fig. 13 Von-Mises stress plot for riveted eye

D. Comparison of Results for Standard, Casted and Riveted Eye Mono Leaf Spring

Table IV shows the comparison of the results for three different eye designs considered.

TABLE IV
COMPARISON OF STANDARD, CASTED & RIVETED EYE MONO LEAF SPRING

Parameter	Standard eye	Casted eye	Riveted eye	%age variation (with standard eye)	
				Casted	Riveted
Load (N)	50	50	50	-	
Deflection(mm)	97.508	102.82	108.36	5.44	11.12
Equivalent stress (MPa)	690	667	778	3.3	12.7
Weight (kg)	10.198	11.23	3.78	10.11	62.9

It is observed from Table IV that under the application of same static load of 50 N and similar joint rotation, the deflections for the standard, casted and riveted eye mono leaf spring are 97.5mm, 102.8 mm and 108.36 mm respectively. The standard eye mono leaf spring is found to be stiffer among three. It is also observed that the equivalent or Von-Mises stresses induced in the standard, casted and riveted eye mono leaf spring are 690 MPa, 667MPa and 778MPa respectively. The weight of the leaf spring for standard, casted and riveted eye mono leaf spring is found to be 10.19kg, 11.23kg and 3.78 kg respectively. The riveted eye mono leaf spring is found to be lightest among the standard, casted and riveted eye.

V. Conclusions

The following conclusions are made from the results discussed:

1. Among three eye designs, standard eye mono leaf spring has the least deformation under the similar loading conditions.
2. Casted eye mono leaf spring has minimum Von-Misss stress among three eye designs for similar loading conditions.
3. Riveted eye mono leaf spring has least weight among three eye designs considered. Weight reduction of 62.9% is possible by replacing standard eye mono leaf spring with riveted eye mono leaf spring.

References

[1] M. M Shokrieh, and D. Rezaei, "Analysis and optimization of composite leaf spring," *Composite Structures*, vol. 60, no. 3, 2003, pp. 317–325.

[2] Vinkel Arora, Gian Bhushan, & M.L. Aggarwal, "Eye design analysis of single leaf spring in automotive vehicles using CAE tools." *International Journal of Applied Engineering and Technology*, vol. 1, 2011, pp 88-97

[3] M. Senthil Kumar, and S. Vijayaranjan, "Analytical and experimental studies on fatigue life prediction of steel and composite multi-leaf spring for light passenger vehicles using life data analysis," *Materials Science*, vol. 13, no. 2, 2007, pp. 141-146.

[4] H. A. Al-Qureshi, "Automobile leaf springs from composite materials", *Journal of Material Processing Technology,* vol. 118, 2001, pp.58-61

[5] Gulur Siddaramanna, Shiva Shanker, and Sambagam Vijayaragan, "Mono composite leaf spring for light weight vehicle -design, end joint analysis and testing" , *Materials Science*, vol. 12, no. 3 , 2006, pp. 220-225.

[6] I. Rajendran, and S. Vijayarangan, "Design and Analysis of a Composite Leaf Spring" *Journal of Institute of Engineers India* , vol. 82, 2002, pp.180 –187.

[7] M. M. Patunkar, and D. R. Dolas, "Modelling and Analysis of composite leaf spring under the static load condition by using FEA" *,International Journal of Mechanical & Industrial Engineering*, vol. 1, no. 1, 2011, pp.1-4.

[8] S. Chantranuwathana, K. Panichanun, Preedanood, P. P .W. Prakarn, and P. Kruo-ongarjnukool, "Experimental verification of leaf spring model by using a leaf spring test rig" at 23rd conference of *Mechanical Engineering Network* of Thailand, 2009, pp. 123-131.

[9] Peiyong Qin, Glenn Dentel, and Mikhail Mesh, "Multi-Leaf Spring and Hotchkiss Suspension", ABAQUS Users' Conference, 2002.

[10] Vinkel Arora, Gian Bhushan, and M. L Aggarwal," A Comparative Study of CAE and Experimental Results of Leaf Springs in Automotive Vehicles" *,International Journal of Engineering Science & Technology,* vol. 3, no 9, 2011, pp. 6856-6866.

[11] Krishan Kumar, Vinkel Arora, Gian Bhushan, and M.L. Aggarwal, "CAE simulation approach for static and dynamic analysis of leaf springs."*3rd International Conference on Production and Industrial Engineering (CPIE-2013), NIT Jalandhar*, *India,* March 29-31,2013, pp 143-153.