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Performance of Hybrid Nanocomposite Material Leaf Springs Subjected to Drop Weight Impact Test

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Abstract

In the present scenario, nanocomposite materials are widely used in automobile applications replacing traditional materials. Weight reduction without compromising the functional requirements is addressed in this article. One of the vital elements in the automobiles is leaf spring suspension system. This paper describes the replacement of conventional metallic leaf springs, with that made of composite materials with a proper and adequate lay-up (structure). The dimensions of conventional leaf spring (commercial) trucks are used to construct and manufacture the die. The constant cross-sectional area of three leaves (assembly) of composite materials reinforced with the fiber of glass, carbon and a mixture of both were fabricated by using hand lay-up techniques. The fabricated composite leaves were exposed to a low-velocity impact, a possible simulation of load tyre interaction. For testing the composite leaf springs with low-velocity impact, test-setups were made in the laboratory, framed with loading set-up. The flexural deflection due to different drop weights is the criterion for relative performance. Apart from all kinds of investigation, the nanocomposite leaf spring outperformed at the 300 mm drop test and it was recommended.

Keywords

Nanocomposite, Leaf springs, Impact test

Introduction

Automobile industries are concerned with reducing weight for fuel-saving, focusing thereby on innovations without compromising on driving comforts. Car manufacturers are concerned about saving fuel to reduce air pollutants and following environmental laws. To increase fuel efficiency the weight of the vehicle should be reduced which can be done by optimization and by an improved manufacturing process.

In this regard, it is important to optimize the subsystem of each vehicle and its mechanical assemblies with a lightweight design. The suspension system is an area where the reduction of un-sprung elements can reduce weight. Leaf spring in automobile contributes 10 - 20% of the weight of the vehicle and by replacing them with leaf springs manufactured by nanocomposites the suspension mass can be decreased. Conventional steels can be easily replaced by composites which are light in weight and with improved mechanical properties [1, 2]. Mostly they concentrate on composite materials for corrosion resistance, damping quality and high strength-to-weight ratio, besides easier maintenance. Leaf spring with lightweight design improves ride comfort and handling stability and reduces energy consumption in many areas. Fiber-reinforced composites have been used because of their excellent capacity to store elastic energy [3] without compromising on the carrying capacity and with lightweight design. The focus of researchers earlier was to design [4, 5], fabricate and test for fatigue and modal characteristics of composite leaf spring. Stiffness is an important characteristic of composite leaf spring, which contributes to ride comfort and handling stability of vehicles and therefore requires accurate prediction. This characteristic can be predicted by the finite element method and experiment tests. Finite element method and experiments done on a single glass fiber-reinforced composite leaf spring designed showed errors between design stiffness and actual stiffness [6, 7]. For the same size, higher stiffness and better fatigue properties were seen in composite leaf springs than in steel leaf springs [8].

The application of composite materials in place of steel leaf springs will not only meet the stiffness requirement but also cater to the need for the damping of the drive system, facilitating better vehicle dynamics. Numerous researchers have dedicated their time and energy to the development and application of composite materials for automobiles. This includes mostly structural parts. Sugiyama et al. initiated a non-linear elastic model of leaf spring for sports vehicles [9]. It was observed by many researchers that composite leaf spring enabled a reduction in stress and weight, in addition to a rise in natural frequency, stiffness and fatigue life [10-13]. Sancaktar and Gratton [14] illustrated the design and manufacture of a composite leaf spring for a solar-powered vehicle; unidirectional E-glass roving impregnated with epoxy resin was used for the composite leaf spring. Energy-based variation method in non-linear geometric analyses of leaf spring by the Lagrangian analysis [15, 16] has also been reported. The woven wrapped composite springs have been investigated by a few authors. The results have shown that composite could be used for vehicle suspension, meeting the requirement for reduced weight [17, 18]. Krall and Zemann [7] investigated the dynamic behavior of carbon fiber reinforced plastic (CFRP) leaf springs. Impact test and shaker test were done for CFRP leaf spring. The tests were investigated at low temperatures. The results indicated that at lower temperatures the model damping increased. At higher temperatures, a possible change of static of matrix from glossy to rubbery state could be expected. Injection moulded thermoplastic leaf springs reinforced with discontinuous fiber were investigated for flexural/creep performance.

The research gap of this investigation is, as it realized the application-oriented investigations were limited [19]. Conventional researchers proposed the composite leaf spring by fabrication and tested the simulated leaf spring specification and material properties [20, 21]. This investigation is unique by fabricating the glass fiber reinforced composite leaf spring to actual setup, similarly, carbon fiber reinforced composite leaf spring, as well as glass and carbon fiber reinforced composite leaf spring. The fabricated composite leaves were exposed to a low-velocity impact, a possible simulation of load tire interaction was involved. Hence the compatibility of a specific application was planned to investigate.

A nanocomposite leaf was used to replace the seven metallic leaf springs under static conditions of design parameters and optimization. Three spring leaves used in a commercial mini truck were replaced by composite leaf spring, (of dimension related to conventional leaf spring) made of bidirectional glass fiber reinforced plastic (GFRP), bidirectional CFRP and hybrid bidirectional glass-carbon fiber reinforced plastic (G-CFRP). Such springs were exposed to low-velocity impact, with a laboratory fabricated with set-up. Low-velocity impact test rig, a laboratory loading set-up was used. The main objective was to evaluate the composite leaf spring relative to the conventional leaf spring considering load, stiffness, and weight saving.

Materials and Method

Material selection

The materials for the aimed composites like GFRP, CFRP, and G-CFRP were selected. Glass fiber mats (600 gsm), LY556 epoxy resin and HY951 hardener were employed. carbon fiber mat, glass fiber mats were used.

Synthesizing composite leaf springs

From an existing conventional assembly, leaf springs were taken and used for the designing and manufacturing of die set-up. Three types of spring leaves such as GFRP, CFRP, and G-CFRP were fabricated. The composite laminates were fabricated using hand lay-up methods. For fabricating the GFRP laminates, glass fiber mats (600 gsm) were cut into a dimension of three specially designed dies each of 18 layers. The matrix material used was LY556 epoxy resin and HY951 hardener in the ratio of 10:1 by weight. Wax was applied on the top surface of the die to get a good surface finish and also to ensure easy removal of the leaf from the die. The glass fiber mats were laid one upon the other till the required thickness was attained and the resin mixture was applied in between the mats. The same procedures were followed to fabricate the assembly of CFRP laminates, 18 layers of CFRP were laid up. The G-CFRP laminate had 10 layers of glass fiber mat and carbon fiber mat (8 layers). The starting and the middle of the laminate were coated with a glass fiber mat. The ending layer was coated with a carbon fiber mat. Also, in the lay-up carbon fiber and glass fiber were placed alternately. The various fabricated composite leaf springs are shown in figure 1.

Experimental details

The different composite leaf springs and the conventional metallic springs were tested for low-velocity impact with loading set-up. The laboratory loading set-up was fabricated using structural steel. The model of the load-carrying fixture was done by solid works as shown in figure 2.

The impact load was applied through load carrying fixture weighing 5 kg. The loading fixture was made to fall through different drop heights as 300 mm, 450 mm, and 600 mm. A view of the fabricated low-velocity impact test rig is shown in figure 3.

Figure 1: Fabricated composite leaf springs.

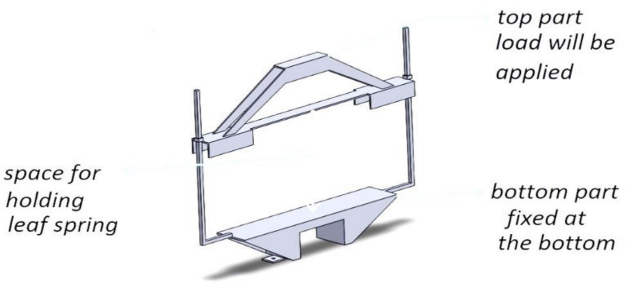

Figure 2: Leaf spring holding fixture assembly.

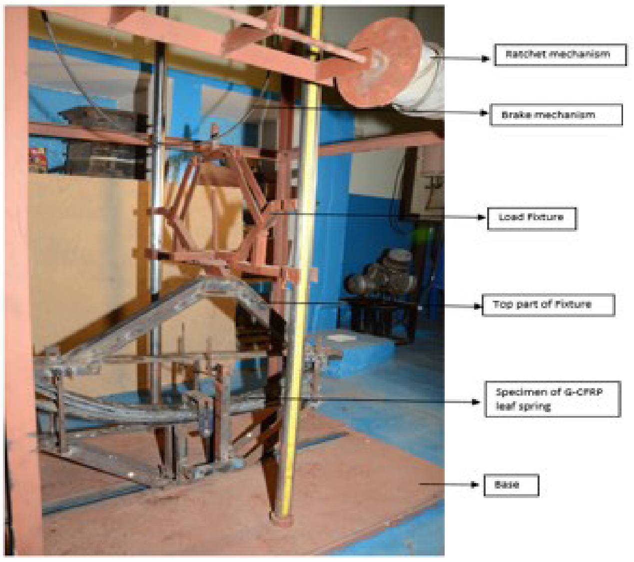

Figure 3: Low-velocity impact test rig.

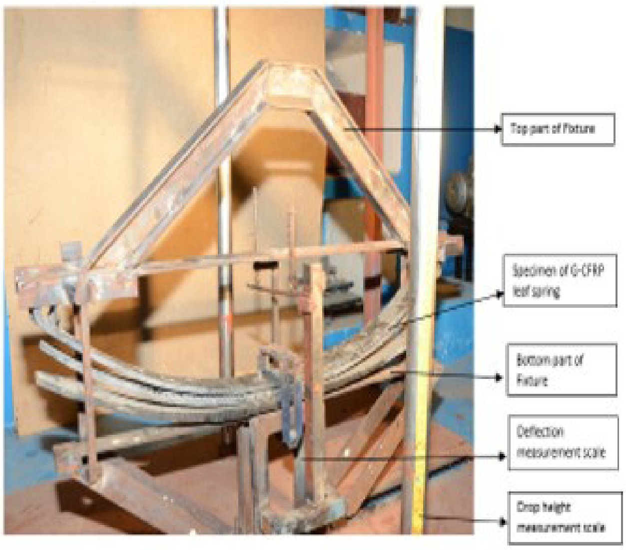

Figure 4: Leaf spring was placed in the fixture.

Table 1: Low-velocity impact test for various leaf springs at some specific trails.

Trial	Falling height in mm	Deflection in mm			
		GFRP	CFRP	G-CFRP	Conventional leaf spring
First	300	43	35	28	24
	450	52	43	36.5	30
	600	63	56.5	47	38
Tenth	300	42.5	34.5	27.5	24
	450	52	42.5	36	30
	600	62.5	56	47	38
Twentieth	300	42.5	34.5	27.5	24
	450	51.5	42.5	35.5	30
	600	62.5	56	46.5	38

Table 2: Impact stiffness for various leaf springs at some specific trails.

Trial	Falling height in mm	Impact stiffness			
		GFRP	CFRP	G-CFRP	Conventional leaf spring
First	300	6.97	8.57	10.71	12.5
	450	8.65	10.46	12.32	15
	600	9.52	10.61	12.76	15.78
Tenth	300	7.05	8.69	10.90	12.5
	450	8.65	10.58	12.5	15
	600	9.6	10.71	12.76	15.78
Twentieth	300	7.05	8.69	10.90	12.5
	450	8.73	10.58	12.67	15
	600	9.6	10.71	12.90	15.78

The assembly of leaf springs was loaded in the machine as shown in figure 4. The flexure deflections of the various composite leaf springs and those of the conventional ones were measured for different drop heights. Table 1 furnishes the results of the low-velocity impact test for various leaf springs at some specific trails in specific first, tenth and twentieth trails. Similarly, table 2 demonstrates the impact stiffness for various leaf springs at some specific trails and table 3 expresses the percentage of deflection for various leaf springs at some specific trails.

The deflection and percentage of deflection for the measurements/observations made for some specific trails such as first, tenth and twentieth trials are shown in figure 5 to figure 10. Figure 5 explains graphically about first trial for various leaf springs with deflection. It gives visual comparison. Similarly, figure 6 presents the percentage of change in deflection for the first trial, figure 7 exhibits tenth trial for various leaf springs with deflections, figure 8 shows the percentage of change in deflection for the tenth trial, figure 9 demonstrates twentieth trial for various leaf springs with deflections, and figure 10 shows the percentage of change in deflection for the twentieth trial.

Table 3: Percentage of deflection for various leaf springs at some specific trails.

		Percentage of deflection			
Trial	**Falling height in mm**	**GFRP**	**CFRP**	**G-CFRP**	**Conventional leaf spring**
First	450	20.5	23.6	29.5	23.6
	600	47.0	61.8	68.1	57.8
Tenth	450	22.3	24.0	32.5	23.6
	600	47.7	62.9	72.0	57.8
Twentieth	450	20.8	24.0	30.2	23.6
	600	47.7	62.9	69.7	57.8

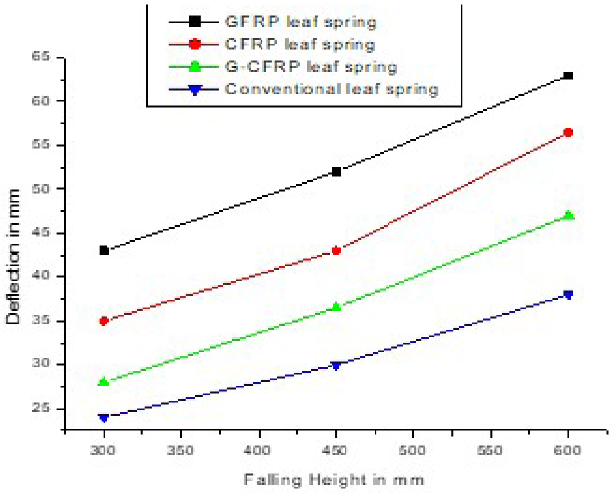

Figure 5: First trial for various leaf springs with deflection.

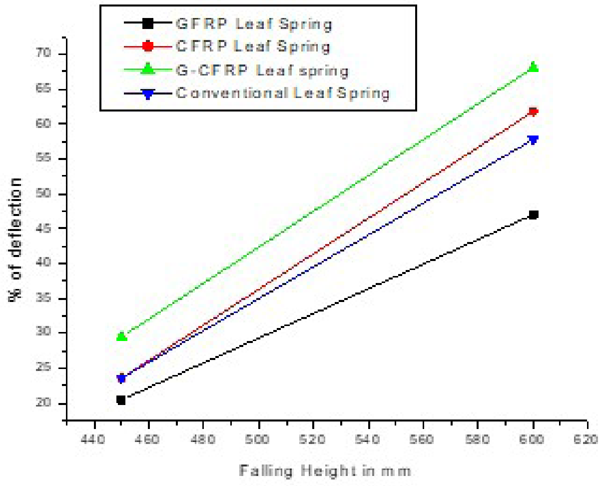

Figure 6: The percentage of change in deflection for the first trial.

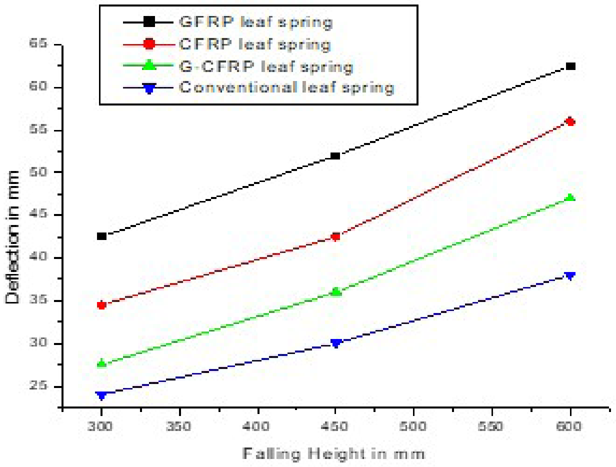

Figure 7: Tenth trial for various leaf springs with deflections.

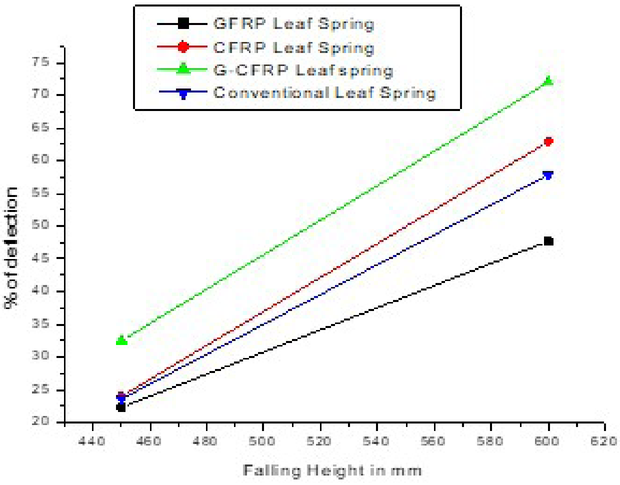

Figure 8: The percentage of change in deflection for the tenth trial.

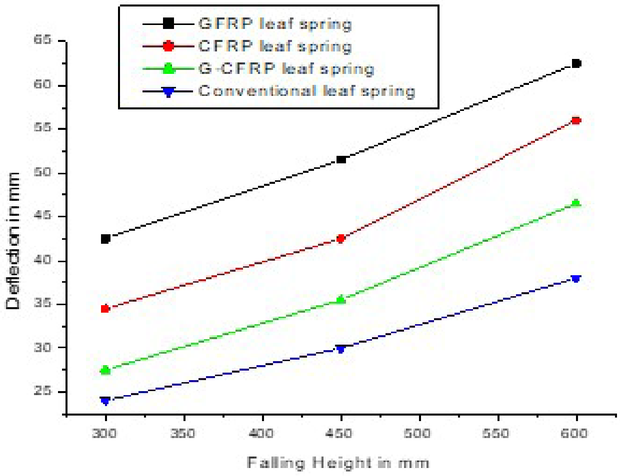

Figure 9: Twentieth trial for various leaf springs with deflections.

Results and Discussion

Both the conventional (steel) leaf springs and the composite materials were subjected to drop weight impact. The relative responses of the springs in terms of deflection (flexure) were monitored. The tests were conducted in up to 20 trials. The observations are presented in table 1. It is seen that the conventional metallic spring exhibits identical deflection in variance with a number of trials, while the composite springs exhibit deflection sensitive to the condition of impact. Normally the composite materials (owing to their heterogeneous structure) exhibit structural stiffness sensitive to loading. Also, during impact, the structure may absorb a certain amount of energy, in addition to possible crack arresting

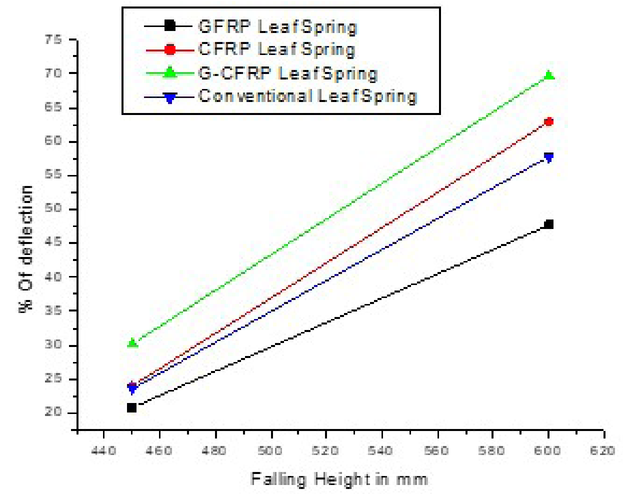

Figure 10: The percentage of change in deflection for the twentieth trial.

by the reinforcement. This can contribute to the arresting by the reinforcement and consequently to the rise in stiffness of the composite structure with loading.

It is seen that springs of composite material exhibit relative reduced flexure resistance compared with metallic springs. Among the composite material springs, hybrid G-CFRP springs exhibit higher-order flexural resistance also closer to metallic springs. The reduction in flexure resistance of the composite material springs could be attributed to the material with impact loading. The observed difference in flexural resistance of GFRP or CFRP composite could be attributed to the difference in flexural characteristics of glass and carbon fibers. During the first trial, the GFRP composite spring exhibited a relatively reduced order of percentage of rise in deflection with a rise in height of the drop. While CFRP composite spring exhibited almost a trial identical to that of metallic spring, Hybrid leaf spring exhibited a higher-order percentage of rise that could be attributed to the difference in the flexure characteristics of carbon and glass fibers.

After the tenth trial, the metallic spring exhibited flexure resistance, identical to that of the first trial, in which the springs of composite material exhibited a marginal improvement in flexural resistance. This could be attributed to the change in stiffness of the composite structure with increased loading/impact.

It is seen that after the twentieth trial, GFRP composite spring exhibited only a marginal change, while CFRP or GFRP composite springs exhibited relatively a mild reduction in flexural deflection. Also, as with the other trials, after twentieth, GFRP composite spring exhibited the least order percentage of change in deflection for a 150 mm rise in higher deflection. All the springs exhibited a rise in impact stiffness of the composite springs tending to rise with the number of hits/trials. Among the composite leaf springs, GFRP exhibited higher order deflection, while the metallic leaf springs the least. Also, mostly a trend change could be seen at 450 mm drop height.

It is seen that among the composites GFRP spring exhibits the least percentage of rising in normalized deflection for the drop height of 150 mm. This can be attributed to better flexural damping in GFRP. Typical variation of percentages of a rise in normalized deflection relative to the initial drop height of 300 mm is illustrated in the figure. It is seen that among the springs of composite materials, the GFRP spring exhibits the least rise indicated by better shock absorption/damping quality of the spring. Both CFRP and the metallic spring exhibit identical response (in this case) percentages of rising in deflection to drop weight impact.

Conclusion

In this investigation, three different composite leaf springs were fabricated and tested. The results were compared with conventional steel leaf spring performance. From the observations on the response of both metallic leaf springs and springs of composite materials, the following conclusions have arrived are: All springs exhibit increasing deflection with drop height. However composite springs exhibit deflections depending on the cumulative impact. Among the springs made for the study, the GFRP composite springs exhibit the least resistance to impact loading. The relative response of the springs in terms of percentage of change in deflection with respect to 300 mm drop height in each of the set of trials was evaluated. With all the trials, the GFRP composite springs exhibited the least percentage of change in deflection. All the composite springs exhibit a marginal rise in impact stiffness. G-CFRP composite springs can be a substitute for the conventional metallic springs. The least order percentage change in deflection observed with GFRP composite springs is attributable to the enhanced energy absorption suggesting that such springs can facilitate better riding comfort. Hence with increasing content of reinforcement GFRP can also be a substitute for metallic springs. Within the limitations of the study the results and conclusion were presented. The proposed composite shall be extended to test with other types of springs.

Acknowledgements

None.

Conflict of Interest

None.

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