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Research Article

Fabrication and Testing of Composite Leaf Spring for Light Passenger Vehicle

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Abstract

Present day we can find many metallic leaf springs commonly used for the suspension of light weight to heavy weight vehicles. It is found that the conventional metallic leaf springs add significant static weight to the vehicles and reduces their fuel efficiency. As composites are the advanced materials having higher strength to weight ratio and corrosion resistance feature they are found to be the potential materials for replacing these conventional metallic leaf springs without giving up the strength and by reducing the structural weight substantially. Therefore in this paper composite leaf spring is fabricated using hand lay-up vacuum bagging technique for composites manufacturing to replace metallic leaf spring of light passenger vehicle. Experimental tests are performed to compare the load carrying capacity and stiffness of composite leaf spring with metallic one and also the fabricated composite leaf spring is fitted to the vehicle and its performance under actual working conditions are studied.

Keywords: *Composite materials, Leaf spring, Light passenger vehicle, Vacuum bagging technique.*

1. Introduction

Recently automobile industries are focused on reducing the static weight of the vehicles to improve their fuel efficiency and reduce the cost. It is found that leaf springs add significant weight to the vehicles. Strain energy of the material becomes a major factor in designing the leaf springs. Composite materials have the higher strain energy capacity because of lower modulus and density. Therefore the composite materials become the strong candidate for fabricating the leaf springs to reduce their structural weight (Al-Qureshi, 2001). Other important characteristics of composites such as higher strength to weight ratio, fatigue strength, corrosion resistance, natural frequency and fail-safe capability made them excellent for leaf spring applications (Shokrieh and Rezaei, 2003). Composite leaf spring was designed and fabricated for solar powered vehicle (Sancaktar and Gratton, 1999). Unidirectional E-glass roving impregnated by an epoxy resin was used for the fabrication. The primary objective was to provide an understanding of the manufacture, use, capabilities of composite leaf springs and to reduce the vehicle weight. Analysis, design and fabrication of a composite mono leaf spring with similar mechanical and geometric properties as that of multi leaf steel spring was presented for the suspension of a compact car (Al-Qureshi, 2001). Genetic algorithm was proposed for the optimal design of composite mono leaf spring to replace the seven-leaf steel spring (Rajendran and Vijayarangan, 2001). Geometrical parameters of the composite leaf springs were optimized and 75.6 % weight reduction was achieved compared to the existing steel leaf spring. Composite materials were also used to fabricate helical (Chiu et al., 2007) and elliptical springs (Mahdi et al., 2006) for vehicle suspension to have the advantages of light weight, corrosion resistance, high degree of durability and minimum cost. Unidirectional laminates were used to attain the maximum load supporting capability and higher spring constant.

In the present work, a three-leaf steel spring used in passenger cars is replaced with a composite spring made of fiber glass/epoxy composite. Hand lay-up vacuum bagging process of composite fabrication is used. The main objectives are to achieve the weight reduction, compare the stiffness characteristics and to evaluate its performance when fitted to the vehicle.

2. Composite Fabrication Processes

Based on the type of the matrix phase materials composites are classified as polymer, metal and ceramic matrix composite materials. Various techniques have been developed for the fabrication of above said composites. Further there are two types of polymer matrix materials: thermoplastics and thermosets. In the present work thermoset matrix material (epoxy) with E-glass long fibers are used in the fabrication of composite leaf spring. Various techniques such as manual hand lay-up and machine assisted spray-up, filament winding, pultrusion, and resin transfer molding have been developed for the

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fabrication of thermoset matrix composites (Chawla, 2006). Further the fabricated composites are cured at room temperature and pressure or at high pressure conditions using vacuum or pressure bag or at high pressure and temperatures conditions using autoclave methods. In the present work Hand lay-up vacuum bagging composite fabrication process is used for making the composite leaf spring.

2.1 Hand Lay-Up Vacuum Bagging

In hand lay-up vacuum bagging method of composite fabrication, the fibers are laid on the mould by hand and matrix material is applied by brushing or spraying. Staking of the layers is done to get the required thickness. Simultaneously the deposited layers are densified with rollers. Then by vacuum bagging method the atmospheric pressure is used to hold the matrix or resin-coated components of a lamination in place until the adhesive cures.

2.2 Vacuum Bagging Principle

The principle of the vacuum bagging process is shown in Fig.1. It consists of vacuum pump, release film, perforated film, breather material, vacuum bag, mastic sealant etc. (WEST SYSTEM® Epoxy, 2010). In this method of composite curing the laminate after the hand lay-up is placed on a platform along with the mould. Then it is covered with a release film. This film is used to avoid the breather material coming in contact with laminate. Release films are made from the specially treated polyester fabric so that matrix material will not bond to it. Before placing the breather cloth over the release film a perforated film is used in conjunction with the release film to hold the resin in the laminate at high vacuum pressures. Breather cloth is used to evacuate the air from all parts of the envelope. Mosquito screen or fiberglass cloth can be used as the breather cloth. Finally the entire envelope is covered by a polyethylene bag and it is made airtight using mastic sealant. Now this airtight bag is provided with a vacuum pump. Vacuum pump evacuates air from the envelope. As a result air pressure inside the envelope reduces whereas air pressure outside the envelope will be one atmosphere. The laminate kept within the envelope is subjected to the uniform atmospheric pressure over its surface. The excessive matrix material is squeezed out from the laminate and uniform thickness and higher strength is achieved for the laminate. The pressure differential between the inside and outside of the envelope determines the amount of clamping force in the vacuum bag method of composite curing. With the complete evacuation of the air from the envelop and making the vacuum bag to be air-tight by perfect sealing the maximum possible pressure that can be exerted on the laminate is one atmosphere.

2.3 Leaf spring fabrication steps

a) Preparation of mould

Initially the dimensions of the metallic leaf spring (light passenger car rear leaf spring) are noted. According to the dimensions the mould is constructed by using sheet metal of thickness 2 mm. The prepared mould is polished with wax, (which acts as releasing agent) in order to avoid sticking of the composite resin after curing.

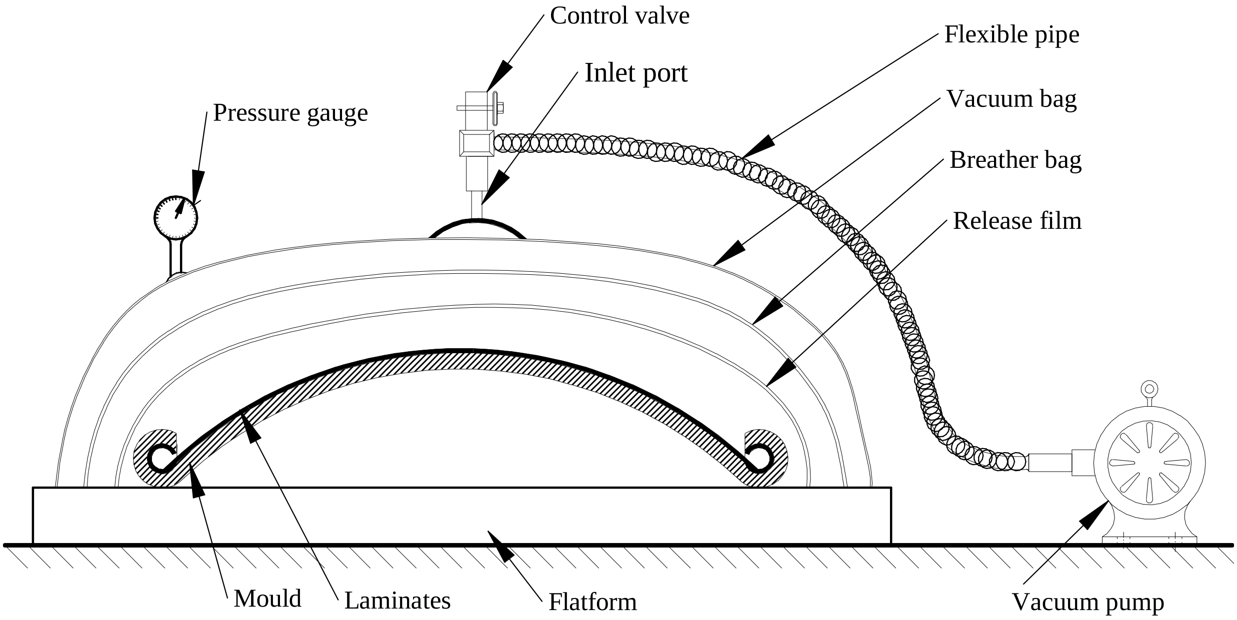

Fig.1 Principle components of vacuum bagging process

b) Making of vacuum bag

In the present work a polyvinyl-crylate film of thickness 0.25 mm is used for making the vacuum bag. Length of the bag is taken bigger than the mould to facilitate easy removal of the mould from bag after curing. Bag is sealed air tight such that no air enters inside from the surrounding. The sealing is done by mastic sealant. The bag is sealed at all its sides and one end is kept open to insert the component after hand lay-up process. At the centre of the bag on upper surface the vacuum inlet port is provided by making a hole to the bag.

c) Hand lay-up procedure

The total amount of glass fiber cloth needed to construct the composite leaf spring is calculated based on the dimensions of the existing metallic leaf spring and the thickness of each lamina. Then the glass fiber cloth is weighed on digital weighing machine. Corresponding equal to this weight epoxy resin is taken and 10% hardener is added to it. Resin hardener mixture is mixed thoroughly and stirred, till a gel like appearance take place.

- The glass fiber cloth is placed on a leveled surface and any air trapped between the cloth and surface is removed (Fig.2).
- After the preparation of resin-hardener mixture it is applied on the entire surface of the cloth in order to wet it. The wetting is done equally by moving a hand roller on the cloth surface so that fiber should not separate from the cloth (Fig.3).
- Then according to the dimension of the leaf spring the laminas are made by cutting the wetted cloth with a sharp cutter (Fig.4).
- Simultaneous laying of laminas on the mould is done to the required thickness of the laminate; suppose we want to construct a 7.5 mm thickness laminate then 30 laminas must be layered up because the thickness of each lamina is 0.25 mm in the present case (Fig.5).
- Finally after the process of laying the laminas a cover plate is placed on the entire laminate over this cover plate a breather material is covered around the entire laminate and mould. The function of this breather material is to breathe air from the bag or envelope and not allow the resin to enter the pump. Enamel cloth, cotton cloth; mosquito net etc. may be used as breather material.
- After covering the breather material the whole assemble (mould, laminate, cover plate and breather material) is placed inside the vacuum bag and the open end is sealed airtight. Vacuum pump is connected through a flexible hose to the vacuum bag. Connections are checked and a dial gauge is fixed to the pump in order to monitor the vacuum pressure. After checking all the connections the pump is switched-on and the air inside the vacuum bag is removed slowly from the vacuum bag. The vacuum pressure is created inside the vacuum bag so that there is equal and even distribution of pressure on the entire surface of the laminate (Fig.6).
- The pump is continuously kept running for about 8 hrs. After that the component along with the mould is removed from the bag and allowed to get cured at room temperature for 24 hrs. Now the component is released from the mould carefully without causing any damage to the component. It is finally finished by filing the ends of the component and polished in order to get smooth finish (Fig.7).

3. Testing of fabricated leaf spring

3.1. Testing of composite leaf spring for stiffness matching

Static load is applied at the centre of master leaf of the fabricated composite leaf spring and metallic master leaf spring for stiffness comparison as shown in Figs.8 and 9. Load is increased from 5 kg to 25 kg in steps of 5 kg and corresponding deflection of both composite and metallic master leaf springs are noted as summarized in the Table1. It can be observed that the deflection in the composite leaf spring is more compared to metallic leaf spring. With the increase in the static load the difference in the deflection values is decreasing. This study shows that, for the same dimensions of both the leaf springs stiffness of the composite leaf spring is 18.78 % lower than the metallic leaf spring. However the stiffness of the composite leaf spring can be enhanced by adding a small amount of high specific strength carbon fibers near the neutral axis of the master leaf.

3.2. Testing of composite leaf spring on universal testing machine (UTM)

Both the leaf springs are tested on UTM to know the maximum load carrying capacity. The load is applied gradually up to 150 kg and the deflection is recorded as given in Table.2. Deflection of the leaf spring is 16 % higher than the metallic leaf spring. However the fabricated composite leaf spring has shown the potential to support the maximum load which is supported by the existing metallic leaf spring. Further the weight comparison of both the leaf springs is given in Table.3. It is found that by using the composite material (E-glass/epoxy) for fabrication of leaf spring the structural weight is reduced by 57.23 %.

3.3. Composite leaf spring fitted to the vehicle

Finally the fabricated composite leaf spring is fitted to the light passenger vehicle (Maruti Omni) as shown in Figs.12 (a) and 12 (b). Under the actual working conditions the composite leaf spring performance is found satisfactory.

Fig.2 Laying of glass fiber cloth

Fig.3 Wetting the cloth with matrix (resin & hardener)

Fig.4 Cutting the cloth for required dimensions

Fig.5 Laying the wetted cloth on mould

Fig.6 Structure kept for curing

Fig.7 Finished component (composite leaf spring)

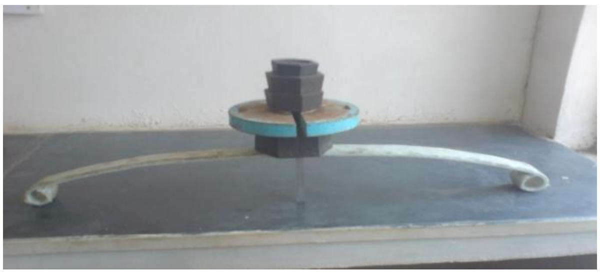

Fig.8 Static load on master leaf of composite leaf spring

Fig.9 Static load on master leaf of metallic leaf spring

Table 1 Deflection comparison and stiffness matching

Load (kg)	Composite leaf spring		Metallic leaf spring	
	Deflection (cm)	Stiffness (kgf/cm)	deflection (cm)	Stiffness (kgf/cm)
5	0.6	8.33	0.5	10.00
10	1.4	7.14	1.1	9.09
15	2.2	6.82	1.7	8.82
20	2.8	7.14	2.3	8.69
25	3.4	7.35	2.9	8.62
Average stiffness (kgf/cm)		7.35	----	9.05

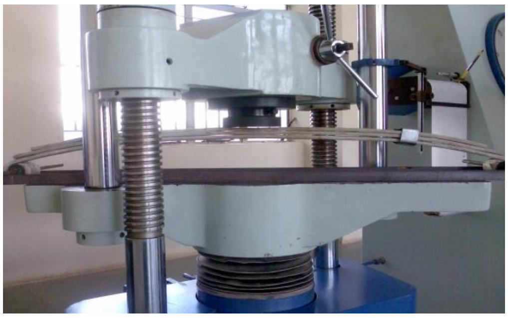

Fig.10 Composite leaf spring loaded on UTM

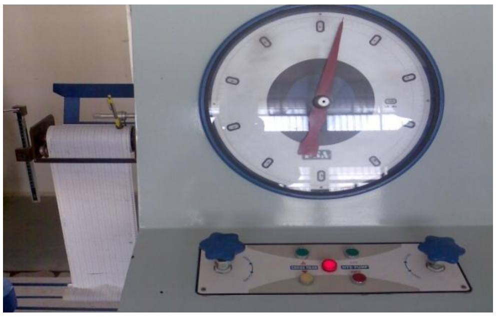

Fig.11 Dial showing the maximum load applied

Table 2 Deflection of both the leaf springs under maximum load

Load (kg)	Composite leaf spring deflection (cm)	Metallic leaf spring deflection (cm)	Difference in deflection (%)
150	8	6.9	16

Table 3 Weight comparison

	Composite leaf spring	Metallic leaf spring	Difference in weight (%)
Weight (kg)	2.78	6.5	57.23

(a)

(b)

Fig.12 Composite leaf spring fitted to the vehicle (a) Rear view (b) Side view

Table 4 Cost estimation of composite leaf spring

Material Used	Quantity	Cost per unit (Rs.)	Total cost (Rs.)
E-Glass fiber	6.5 m.	115	747
Epoxy resin	1.8 kg.	510	918
Labour cost	------	--------	500
Other miscellaneous cost	------	--------	335
Total cost of composite leaf spring (Rs.)			2500

4. Cost comparison

Fabrication cost details of the composite leaf spring is given in Table.4. Total cost incurred in the fabrication of the composite leaf spring is Rs.2500 (only the material and labour cost is considered). Cost of conventional metallic leaf spring as per market price is Rs.3000. This shows that the fabricated composite (E-glass/epoxy) leaf spring is 16.11 % less costly than the metallic leaf spring.

Conclusions

In this paper a glass/epoxy composite multi-leaf spring is fabricated using hand lay-up vacuum bagging composite fabrication technology. The fabricated composite leaf spring has given 57.23 % weight reduction compared to the existing conventional metallic leaf spring. The stiffness of the composite leaf spring is found to be 18.78 % lower than the metallic leaf spring. However the fabricated composite leaf spring has shown the potential to support the maximum static load of 150 kg with comparable deflection as that of metallic leaf spring. Further the fabricated composite leaf spring has shown satisfactory performance under actual working conditions when fitted to the vehicle. From the present study it can be concluded that the composite materials can be used effectively for the fabrication of leaf springs to replace the existing conventional metallic leaf springs to take the advantage of weight reduction and fuel efficiency in light weight vehicles.

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