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Structural Health Monitoring of Fibre Reinforced Polymer Composite Leaf Spring

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Abstract: **The Structural Health Monitoring (SHM) has gained wide acceptance in the recent years as a means to monitor a structure and provide an early warning of an unsafe condition using real time data. Many researchers have shown that, Fiber Reinforced Polymer (FRP) composite leaf springs can be successfully used for suspension systems. This paper emphasizes on developing the SHM system for E-Glass/Epoxy FRP composite leaf springs based on strain sensing.**

Keywords: **Structural health monitoring, Fiber reinforced polymer, Strain-gauge sensors, Composite leaf spring, E-Glass/Epoxy.**

I. INTRODUCTION

The excellent properties of fiber reinforced polymer (FRP) such as high strength and stiffness in combination with a low specific mass and the numerous possibilities of function integration created many opportunities in the industry. FRP composite leaf spring is one of such emerging application area which is taking its heights in the recent past. Safety of the FRP composite leaf spring is one of the major issues to be taken care. In this regard, Structural Health Monitoring (SHM) system for the continuous real-time monitoring, assessment, and damage detection is developed to enhance the safety of FRP leaf spring for the entire period of its service.

Various researchers have contributed to the field of FRP composite materials, fabrication process and structural health monitoring (SHM) in various fields. In which Senthilkumar Mouleeswaran et al. [1] have proposed a Design, Manufacturing and Testing of Polymer Composite Leaf Spring for Light Passenger Automobiles. Prof. A. R. Chaple et al. [2] have proposed Automatic lay-up Process for Manufacturing of FRP Sheets and converted manually operated hand lay-up process into automatic lay-up process. C.K. Clarke et al. [6] have proposed the determination of the point of failure during an over-load in the sequence of a rear leaf spring of a vehicle is presented in terms of fracture surface analysis and residual-strength estimation. M. Baskar Rao et al [10] demonstrate the feasibility of Fiber Bragg Grating sensor and compare its utility with the conventional strain gauges and PVDF film sensors. For this purpose experiments are being carried out in the laboratory on a FRP composite wing of a mini air vehicle (MAV).Victor Giurgiutiu et al [11] have proposed a method of Structural Health Monitoring of Composite Structures with Piezoelectric-Wafer Active Sensors in which use of piezoelectric-wafer active sensors for structural health monitoring of composite structures was developed by some damage analysis in composite structures.

Most of the investigation on SHM and FRP manufacturing, the main focus is to reduce risk of failure and weight reduction. In the present work an appropriate SHM is developed for monitoring the critical parts of the leaf spring i.e. points at which extreme stresses will be induced, the use of the strain gauge sensors allows for locating and describing strain events in space by integrating the fiber reinforced polymer (FRP) composite leaf spring with strain gauge while in leaf spring fabrication. The leaf spring can be monitored continuously, starting from its fabrication to working period. In this paper, distinct method for SHM of composite leaf spring by integration of strain-gauge sensor network has been proposed. The strain gauge sensor network is embedded in fiber-matrix laminates and output leads of sensor network are coupled to strain indicator. The figure 1 shows FRP leaf spring with SHM system fitted to the TATA Ace vehicle.

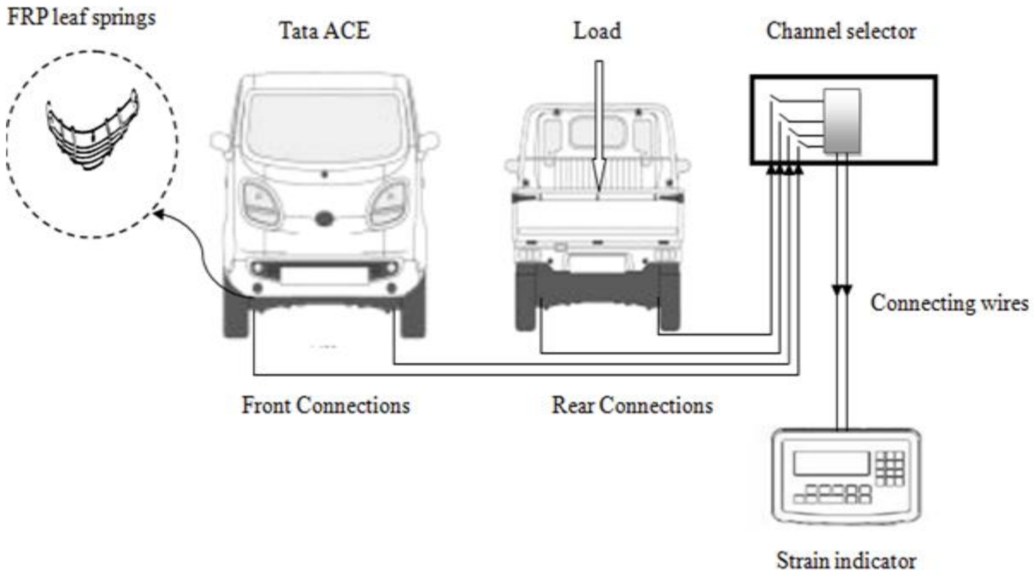

Fig.1 SHM for Tata ACE Suspension System

II. MATERIALS SELECTION FOR FRP COMPOSITE LEAF SPRING

Selection of the suitable material is a key aspect. FRP composite materials consisting of fibres of high strength and modulus embedded in or bonded to resins with distinct interfaces between them. In general, fibres are the principal load carrying members, while the surrounding resins keep them in preferred location and orientation. The material composition selected for mono composite leaf spring are E-glass-60%, Epoxy resin-40%, in which E-glass as fiber material because of which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements. Thus, E-glass fiber was found suitable for this application and the selected glass fiber is woven mat 360 GSM type with diameter of fiber is 0.0074mm, 204 filaments per strand and average thickness of the mat is 2.1mm. A mono-leaf E-glass–epoxy has been used to replace a three-leaf steel spring with nearly an 80% weight savings. In the selection of matrix material Epoxy LY556 with density 1.15-1.20 g/cm^3 and the grade of hardener has been used for this application is HY951. Epoxy is in combination with hardener HY951 cures into hard resin. Hardener HY951 is a low viscosity polyamine. This combination is characterized by good mechanical properties, faster curing at room temperature and good chemical resistance properties.

III. STRAIN GAUGE CIRCUIT FOR INTEGRATION WITHIN FRP LEAF SPRING

There are several methods have been developed for measuring strain, the most common is with a strain gauge, a device whose electrical resistance varies in proportion to the amount of strain in the device. The most widely used gauge, however, is the bonded metallic strain gauge. The metallic strain gauge consists of a very fine wire or, more commonly, metallic foil arranged in a grid pattern. The grid pattern maximizes the amount of metallic wire or foil subject to strain in the parallel direction. The cross sectional area of the grid is minimized to reduce the effect of shear strain and Poisson Strain. The grid is bonded to a thin backing, called the carrier, which is attached directly to the test specimen. Therefore, the strain experienced by the test specimen is transferred directly to the strain gauge, which responds with a linear change in electrical resistance. Strain gauges are available commercially with nominal resistance values from 30 to 3000 Ω, with 120, 350 and 1000 Ω being the most common values. In practice, the strain measurements rarely involve quantities larger than few micro strains (e10^{-6}). There are several configurations for measuring the output of strain gauge, the common configurations are Quarter bridge, Half bridge, Full bridge configurations. In this proposed work, copper-foiled strain gauge circuit is embedded in E-Glass/Epoxy is fabricated into FRP composite leaf spring. Cupper inserts in the FRP materials will increase the strength of the FRP material in addition to Sensing characteristics.

In this work hand layup process is used for the fabrication of FRP leaf spring. Integration of sensor network within the FRP leaf spring is very important event. The strain gauge circuit is developed by using thin adhesive copper strips and strain gauges. Each strain gauge is placed on the critical points of the leaf spring as shown in the Figure 2. In this regard the strain gauges are placed in to leaf spring at constant distances 186mm, 372mm, 558mm and 744mm.

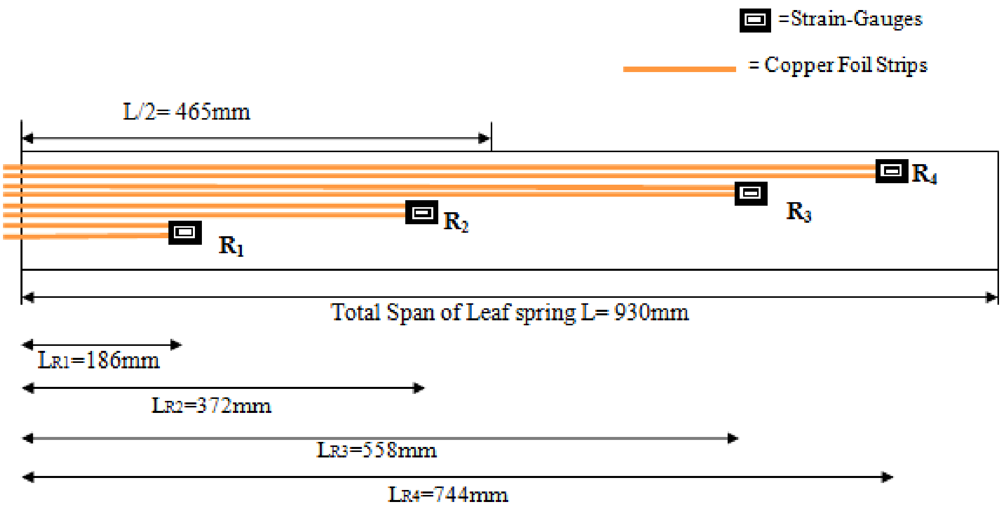

Fig.2 Strain gauge circuit made by copper thin strips

IV. SPECIFICATION OF CONVENTIONAL STEEL LEAF SPRING

A Single steel Leaf spring is considered for this work that includes total length 920 mm arc height of axle seat (camber) 65 mm, width of leaf 60 mm thickness of leaf 8 mm. even though the leaf spring is simply supported at the ends. Related Specifications of Leaf Spring for TATA Ace vehicle is shown in table 1.

TABLE I. Actual Parameter of Conventional Steel Leaf Spring

Parameters	Dimensions
Length	930 mm
Width	45mm
Thickness	30mm
Weight	2.8 kg
Camber height	65mm
Material	Steel 55Si2Mn90
Yield strength	1470 N/mm^2
Tensile strength	1962 N/mm^2
Young's modulus E	2.1×10^5 N/mm^2

V. FABRICATION OF FRP LEAF SPRING

FRP leaf spring integrated with strain gage sensor network is prepared using the hand layup process. The wooden mould is used for this process. Wax is used as releasing agent. The glass fibres are cut in to desired lengths and weighed, so that they can be deposited on the template layer by layer during fabrication. Two tissue mats are used on top and bottom of spring to give a smooth surface finish. This is followed by the uniform application of epoxy resin over tissue mat and then on glass fiber mats. Epoxy resin is applied after placing the each layer of glass mat. The brush is used to spread resin and hardener mixture uniformly and roller is used to remove trapped air. During this lay-up process the sensor circuit is inserted between glass fiber mats carefully when half of the thickness is completed. It is allowed to cure for few hours. Figure 3 and Figure 4 shows the leaf spring preparation using hand layup process. Figure 5 shows the finished FRP leaf springs.

Fig.3 Hand lay-up process

Fig.4 Integration of Sensor network with in fiber-matrix layer

Fig.5 Final finished FRP composite leaf spring

Care must be taken during the individual lay-up of the layers to eliminate the fiber distortion, which could result in the lowering the strength and the rigidity of the spring as a whole, and maintaining the composition of glass fiber and resin as 60%:40%. The duration of the process may take up to 60 min and the mould is allowed to cure for 3-4 days at room temperature.

VI. EXPERIMENTAL ANALYSIS

The experiments were performed on servo–controlled universal testing machine. The leaf spring is mounted in an inverted manner on the test bed. The two ends of the leaf spring are positioned using clamping devices and the uniform load is applied up to when leaf spring gets flattened, that is 142 N showed by Figure 6. In this experiment apply the load gradually from top at the center of the leaf spring. The load versus displacement graph is obtained for two leaf springs from the automatic computerized chart recorder using data acquisition system inbuilt in the machine which is shown in Figure 7.

Fig.6 Testing of FRP composite leaf spring

Fig.7 Plot of load versus displacement

TABLE II. Test Summary

Specimen	CS Area(mm2)	Peak Load (N)	Flexural Strength(Mpa)	Flexural Modulus(MPa)
1	600.00	125.225	25.357	56073.669
2	600.00	141.411	28.636	5717.419
Avg.	600.00	133.318	26.997	30895.544

VII. SHM OF FRP LEAF SPRING

Leaf springs either steel or composite generally fail suddenly by application of load and without prior warning following overload. In a vehicle system the SHM is establishing according to composite leaf spring made by the method of one or more strain responsive members (strain-gauges) may be adapted, in combination with an indicating or monitoring device, to give a warning when the critical predetermined load is applied to the leaf spring so that overloading may be avoided. This may be facilitated by providing one or more strain responsive members in the high strain region of the composite leaf spring. Any structural member incorporates at least one strain responsive member (strain-gauge) within a part at which a strain is induced by a load in use. A signal which is a function of a strain detected by the strain responsive member is communicated to an indicator or monitoring device which registers the applied load causing the strain.

A fiber-reinforced composite leaf spring for determining the magnitude of a strain made by the method according to replacing the steel leaves by composite leaf spring embedded with sensor network and identify the critical failure of leaf spring by using integrated sensor network is coupled to strain indicator. In this work first replace the graduated steel leaves of both front and rear suspensions of a Tata ACE by Fabricated leaf spring, this is followed by individual leaves are assembled together with previously used master steel leaf using a bolt and side clamps as in previous setup. These assembled leaf springs are fixed in to suspension allowance of the vehicle. In this regard the output leads from FRP leaf springs are allowed to connect to strain indicator or monitoring device by using appropriate wires and connectors to close the measuring circuit as per the bridge selected configuration which is shown in Figure 8. Following that to provide power supply to the strain indicator, in this indicator initially the display shows some strain values due to variations, so that before the experiment the reading is set as zero. Subsequently the static loads on the vehicle are applied by incremental known weights, this is followed by take simultaneous readings of strain (mε) with respect to applied loads from strain indicator in different configurations at each suspension of the vehicle (both front and rear).At each load tabulate strain values of all leaf springs independently in the suspension system.

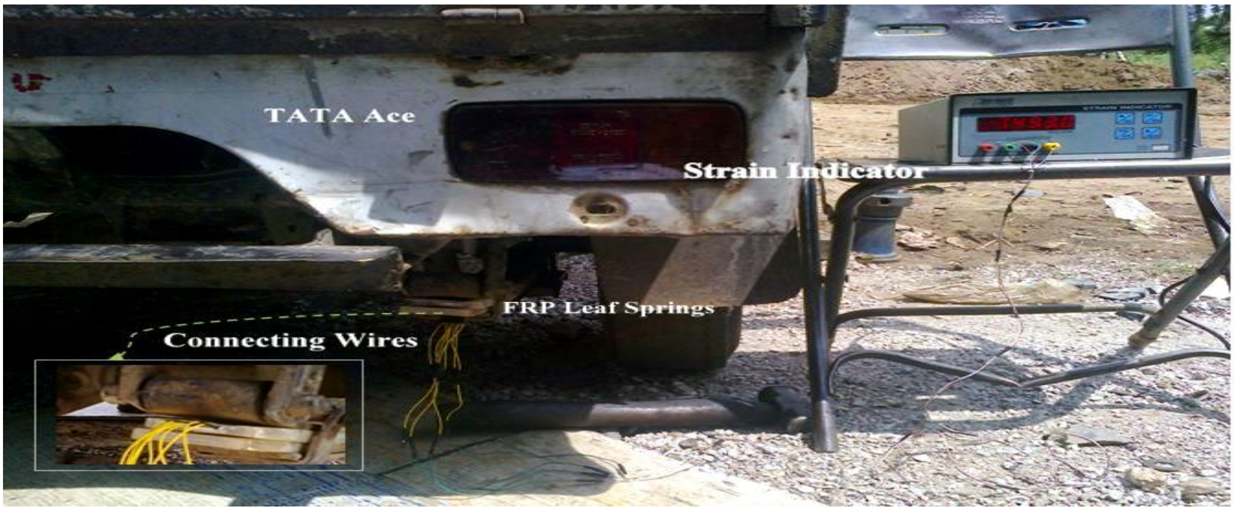

Fig. 8 FRP Leaf Springs are coupled to Strain Indicator

From this evaluation the SHM is introduced by when the maximum strain is occurs within the leaf spring, in which care can be taken by the driver, and in that driver give an attention to load carried by the vehicle in order to protect the vehicle suspension from failures and also increase handling quality and improving ride comfort and performance of the vehicle. From the Figure 9 it is observed that strain increases linearly with respect to applied loads.

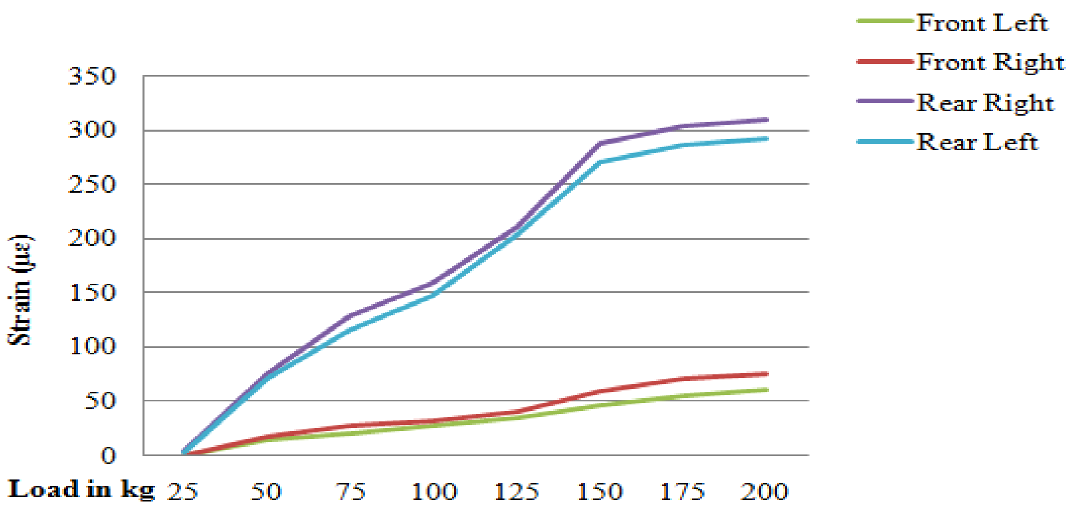

Fig. 9 Strain Distributions between Leaf Springs

VIII. CONCLUSION

The proposed work, Structural Health Monitoring of composite leaf spring led to following specific conclusions:

- Fabrication technique for integrated strain gauge sensor network inside the laminates of FRP leaf spring is successfully proposed by this investigation.
- Mechanical testing of FRP leaf spring is carried out and results are compared with analytical results. Results agree with each other.
- The fabricated FRP leaf springs are successfully fitted to the TATA-ACE luggage carrier suspension and strain distribution of FRP leaf springs are analysed.
- The Structural Health Monitoring system for FRP composite leaf spring is successfully developed.

IX. FUTURE SCOPE OF THIS WORK

This FRP leaf spring integrated with strain-gauge sensor is used as an over-load Indicator. In the vehicle, driver can monitor the weight on axle directly at the working site on real time basis and thus, it enables the driver to avoid overloading in advance.

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