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A REVIEW ON TESTING OF STEEL LEAF SPRING

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Abstract - *This study gives a brief idea about fabrication and testing procedure of steel leaf spring. The efforts have been taken for sequential analysis of leaf spring. It includes static test, fatigue test, macroscopic inspection and metallographic analysis of leaf spring. For the static test, specimens are tested on Universal testing machine (UTM) and numerical analysis is done via (FEA) using ANSYS software. Stresses and deflection results are verified for analytical and experimental results. The fatigue tests are conducted on hydraulic-fatigue testing machine under fluctuating loads. Generally, the origin of premature fracture in leaf springs is at the hole region where there is a high stress concentration. The stress concentrators included the complex geometry of the hole, its sharp corners, notches caused by the bolt thread and various surface defects such as scabs and rolling lines in the starting sheets of unclean steel. For the detail analysis of causes of failures, the fracture surface must be inspected for Macroscopic Inspection test, Chemical analysis and Metallographic Analysis. These tests give detail idea about causes of failure from metallurgical and morphological point of view. Generally there is a steel decarburization on fracture surface during the manufacturing process, which led to inadequate hardness in the springs and the local presence of soft products (ferrite) in the material structure.*

Keywords: Steel Leaf Springs, Static Test, Fatigue Test, UTM, FEA.

1. INTRODUCTION

The suspension leaf spring is one of the potential and most critical component of automobile vehicle which is helping for improving of riding quality of automobile vehicle. The main purpose of springs is to absorb, store and release energy. Leaf plays a vital role in supporting lateral loads, shock loads, brake torque and driving torque. Advantages of leaf spring over helical spring are that the ends of the springs are guided along a definite path so as to act as a structural member in addition to shock absorbing device. This is the reason why leaf springs are still used widely in a variety of automobiles. Leaf spring made of composite materials made it possible to reduce the weight without any increase in load carrying capacity and stiffness of the leaf spring. Therefore, analysis of composite material leaf springs has become essential in showing the comparative results with conventional leaf springs. The geometry of the Steel leaf spring is shown in Fig. 1. The use of composite materials was made it possible to reduce the weight of leaf spring without any reduction on load carrying capacity and stiffness. Since, the composite materials have more elastic strain energy storage capacity and high strength to weight ratio as compared with those of steel, multi-leaf steel springs are being replaced by mono-leaf composite springs. The composite material offer opportunities for substantial weight saving but not always be cost-effective than steel counterparts.

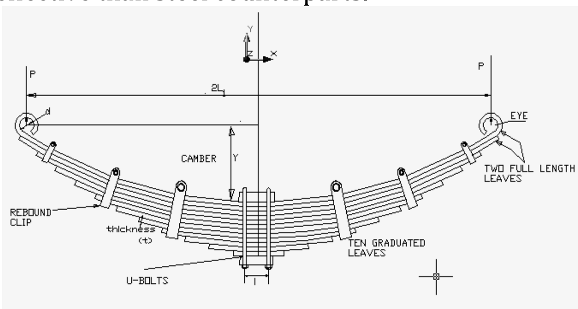

Fig. 1 Leaf spring

Much more research has been done on leaf spring. In order to conserve natural resources and economize energy, weight reduction has been the main focus of automobile manufacturers in the present scenario. Weight reduction can be achieved primarily by the introduction of better material, design optimization and changing manufacturing processes. The suspension leaf spring is one of the potential items for weight reduction in automobiles as it accounts for 10% - 20% of the unspring weight. This achieves the vehicle with more fuel efficiency and improved riding qualities. [3]

Several papers were devoted to the application of composite materials for automobiles & studied the application of composite structures for automobiles and design optimization of a composite leaf spring. Great effort has been made by the automotive industries in the application of leaf springs made from composite materials [1, 2]. Cook B, Owens D [10] showed the introduction of fiber reinforced plastics (FRP) made it possible to reduce the weight of a machine element without any reduction of the load carrying capacity. Because of FRP materials high elastic strain energy storage capacity and high strength-to-weight ratio compared with those of steel, multi-leaf steel springs are being replaced by mono leaf FRP springs [6, 7].

2. PREPARATION OF SAMPLE

Firstly the material is selected based on its mechanical properties. For example, the chemical composition of EN45A spring steel contains 0.61 C–1.8 Si–0.79 Mn–0.02 S–0.024, weight%. The mechanical properties of EN45A are: yield strength of 1147 MPa, ultimate tensile strength of 1256 MPa and fatigue limit of 582 MPa. The selected test material is first heat-treated at 918˚C, and oil-quench hardened. It will temper at 550˚C. This will give a Rockwell hardness of HRC of 42. For the purpose of testing specimens, a steel strip, 76 x 19 x 1.3 mm thick is used which are used in buses. The dimensions of test specimens are varied according to the specific application and loading conditions. The spring manufacturing process, which is conducted entirely, starts from 102 mm wide, 1.3 mm thick sheets of steel obtained by hot rolling. It involves cutting, forming and punching of the leaves, hardening by quenching and tempering, surface finishing by shot peening, and assembly of individual leaves by inserting a bolt through their central hole and fastening them, at the ends, with two clamps. Apart from the selection of material and design procedure, the selection of manufacturing process also determines the quality and cost of the product.

3. TESTING OF LEAF SPRING

3.1 Static Test

In the experimental analysis, the comparative testing of different steel leaf springs will help for drawing the conclusions. The steel and steel leaf springs are tested by using leaf spring test rig. The experimental set up is shown in Fig 2. The leaf springs are tested by recommended standard procedure. The deflection or bending tests of selected spring for comparative study is taken on the universal testing machine. The spring is loaded from zero to the prescribed maximum deflection and back to zero. The load is applied at the center of spring. In the testing, firstly move the plunger up to desired height so that we can fix the fixture and leaf spring for test. Fix the position of fixture. On the fixture place the specimen. Set the universal testing machine. Apply the loads in steps of 20 kg gradually. The vertical deflection of the spring center is recorded in the load interval of 20 Kg. The noted deflection readings will help for comparative study of steel springs.

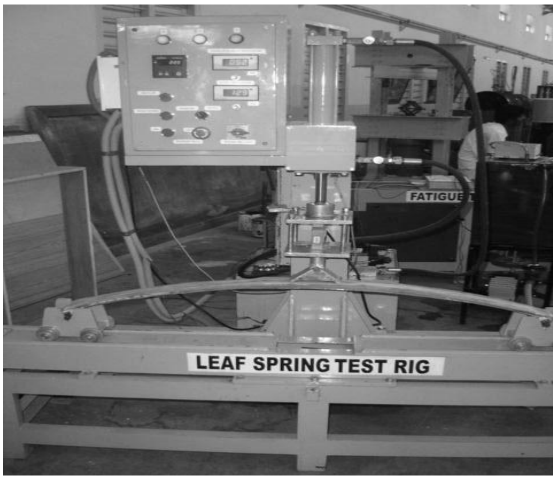

Fig.2 Universal Testing Machine

Fig. 3 shows the linear relationship between the applied load and the extent of reversed bending, which is indication of an elastic behaviour. Flattening the spring required bending it by 97 mm with a 3560 kgf load. The maximum deformation (10 mm departing from the flattened position) is obtained with a load of 3810 kgf. After unloading, the spring regained its initial shape. From the graph, it is clear that the springs are behaves elastically under static loads at high 3600 kgf.

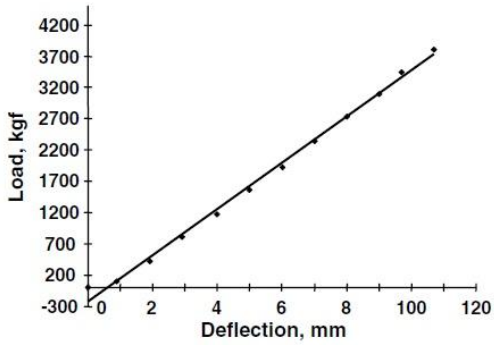

Fig. 3 Load vs. Deflection

3.2 FEA using ANSYS Software

The steel leaf spring is analyzed for static strength and deflection using 3D finite element analysis. The general purpose finite element analysis software ANSYS is used for the analysis. Using the advantage of symmetry in geometry and loading, only one-half of the leaf spring is modeled analyzed. The three dimensional structure of the leaf spring is divided into a number eight-nodded 3D brick elements and five-node 3D contact element are used to represent contact and sliding between adjacent surfaces of leaves. For getting accurate results, more number of elements is to be created. Hence, an aspect ratio of three is maintained in the finite element model. After applying virtual loading the variation of bending stress and displacement values are predicted. Also, analysis carried out for steel leaf spring with bonded end joints. Materials and the results were compared with various steel leaf springs with varying percentage of alloying element. The maximum peel and shear stresses along the adhesive layer are measured. The Fig. 4 shows the displacement pattern of steel leaf spring while apply the loads gradually. The fig. 5 shows stress distribution for steel leaf spring. And fig. 6 shows Contact pressure distribution for steel leaf spring. The similar FEA analysis technique will be used for comparison and design of springs.

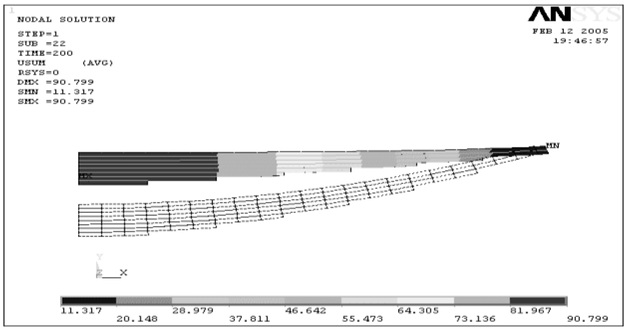

Fig. 4 Displacement pattern for steel leaf spring

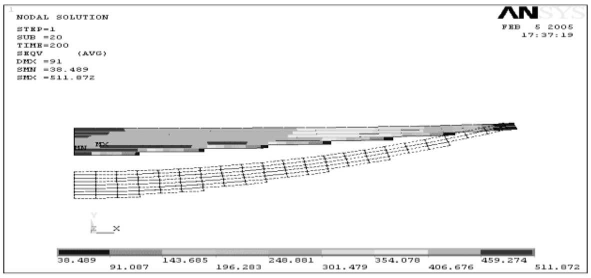

Fig. 5 Stress distribution for steel leaf spring

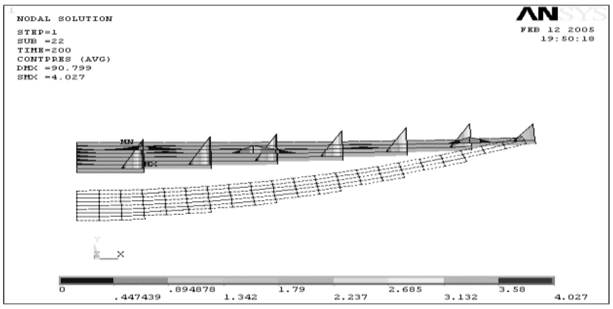

Fig. 6 Contact pressure distribution for steel leaf spring

3.3 Fatigue Test

A fatigue analysis is carried out with the help of hydraulic-fatigue testing machine. The designed and fabricated composite leaf spring is mounted on testing machine and the limit switches are fixed at a span of 50 mm in the vertical direction. This is the amplitude of loading cycle, which is considerably high amplitude. The frequency of one cycle is 66-80 mHz, which is considered to be very low. This leads to high amplitude low frequency fatigue test. During the test the value of strain at location 1 is recorded. The maximum and minimum stresses value is obtained at the first cycle of the composite leaf spring are 299 MPa and 202 MPa respectively. As the number of cycles goes on increasing, the fluctuation in the stress are continuing to a certain level then settling takes place. Under this condition, the maximum and minimum operating stress values are found to be 310 MPa and 208 MPa, respectively. Since, the fatigue (tensile) strength of the composite material is considered as 900 MPa, the stress level obtained from operating stress is 0.33, which is very low and safe. Due to high amplitude and low frequency fatigue analysis, the experimental analysis does not provide final results in the short period. The test is conducted for 100 to complete 25,000 cycles. The variations in stress level are reduced to very low level after 25,000 cycles. It is observed from the fatigue test that there is only a negligible reduction in spring rate (1.5%) and no crack initiation in the spring after 25,000 cycles of fatigue loading. There is large differences in fatigue behaviour of different specimens by effect of the hole geometry. Thus the spring with a cup-shaped hole reached 24,000 loading cycles; on the other hand, the flat-hole springs withstand for more than twice that number (52,000 cycles). This can be described to the increased stress concentration in the cup-shaped holes and which is responsible for earlier failure of leaf spring. Therefore, the cup-hole design is a poor design. The test is finished as soon as cracks become apparent in the master leaf or in more than two supporting leafs. The rectangular shape of the hole in the second leaf (Fig. 7), which was intended to facilitate fitting in assembling the springs, from the fig. 7 it is seen that the largest fatigue cracks are starting at the corners of the rectangular holes. Such corners are quite sharp and acted as highly stress concentrator's area that promotes fracturing. Sometimes, it is not happened. Then there is necessity to go for analytical model for finding the remaining number of cycles of fatigue.

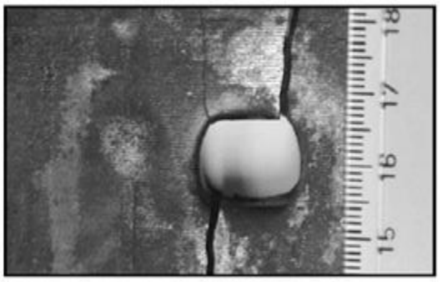

Fig. 7 cracks in rectangular hole after fatigue test

3.4 Macroscopic Inspection

The selected springs are subject to visual and macroscopic inspection with a magnifier. The Fig. 8 shows the view of the fracture leaf, which will occurred in the service. The fracture started at the central hole, in a plane normal to the leaf major axis, with no evidence of a prior plastic deformation. Fig.7 shows the appearance of the fracture surface. Morphologically, the fracture surface is typical of fatigue failure [3]. Thus, it consist of a smooth region including the ring marks extending into the crack origin on both sides of the hole and spanning nearly one half of the fractured area. The remaining material which was unable to withstand the service loads had suddenly broken due to overloading. The crack propagated normally to the main axis of the spring leaf. In the conclusion, the fractographic evidence shows it's a fatigue fracture. Also, the marks observed suggested that the crack originated in the vicinity of the top corner of the hole front as shown in fig.7. This is a region a high stress concentration [4].

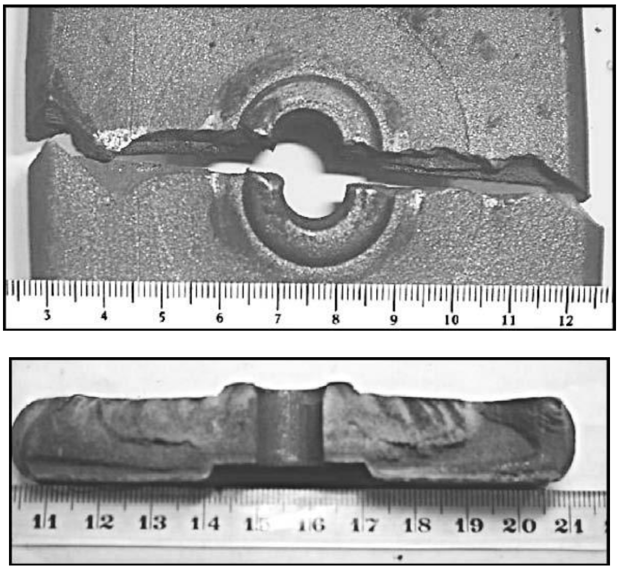

Fig. 8 Photograph of the fractured leaf of a specimen

In addition, the leaves have surface defects on both their outer sides and the hole inner side. Fig. 9 illustrates the condition of the surface of the first (master) leaf in a spring representative of a production batch. As can be seen, the leaf has surface discontinuities in the form of scabs and rolling marks.

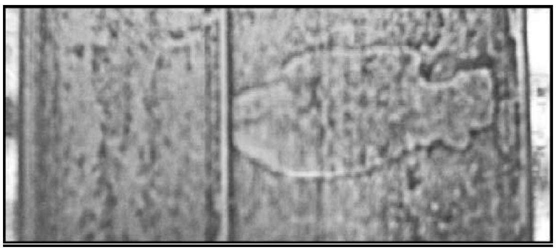

Fig. 9 Surface of a leaf showing rolling lines and scabs.

3.5 Metallographic Analysis

The specimens for metallographic analysis are to be prepared according to ASTM E3 standard. After surface preparation, the material was etched with Nital for microscopic inspection. Particularly, fractured specimens were examined in the quenched and tempered condition; generally, steel is quenched from 860˚C by cooling in oil at 50˚C, and tempered by heating at 490˚C for 45 min. The micrograph of Fig.7 shows the region adjacent to the fracture in a broken specimen in a lengthwise section normal to the rolling surface (Orientation E in ASTM E3 standard). In addition to the tempered martensite structure, which is typical of the quench and temper condition, the material exhibited islands of ferrite, which is the white constituent. This microstructure is consistent with a deficient quenching of the material. The presence of ferrite can considerably reduce the fatigue limit due its soft nature [5]. In order to more precisely assess the efficiency of the industrial quenching operation during the manufacturing process, a quenched leaf was also metallographically examined under the above-described conditions. The as quenched structure is not fully martensitic; rather, the leaf microstructure exhibits a number of scattered white spots revealing the presence of retained austenite. Both retained austenite and its tempering products are softer than tempered martensite and have an adverse effect on fatigue strength. Nevertheless, proeutectoid ferrite was not observed in this sample. These results point out that the quenching operation is not very reliable. The amount of retained austenite additionally depends on the chemical composition of the particular steel, the austenization temperature and time, and the cooling rate. The austenization time is typically 1hr per inch thickness. The austenization temperature is very important in as much as it can alter the amounts of carbon and alloy elements dissolved by austenite, which in turn influence that of austenite ultimately retained. Also, keeping austenite hot, especially during cooling, tends to retard its transformation into martensite.

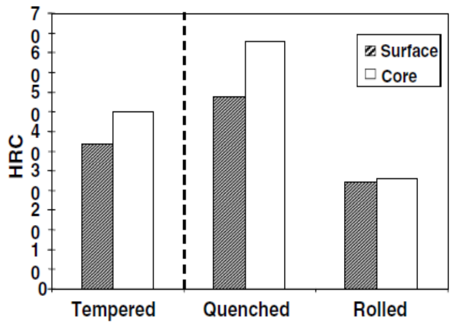

Fig.10 Hardness of the fractured region

Fig. 10 shows hardness of the fractured region tempered as opposed to that obtained after quenching and hot rolling. Measurements are to be made at both the surface and core of each leaf. As can be seen in Fig. 9, the HRC value for the fractured specimen was 18% lower at the surface than in the core The former value is lower than the SAE recommended value (42–49 HRC) [9]. The quenched leaf also exhibited a disparate hardness at the surface and core (49 versus 63 HRC), but little difference between the two was found in the as-rolled condition (27 versus 28 HRC). Based on the previous results, the hardness of the leaf surface was considerably reduced by the thermo mechanical manufacturing process. This was mainly the result of steel decarburization, due to the lack of right control in the protective atmospheres of the heating equipment's (forges and furnaces).

4. PREVENTIVE MEASURES

One effective way of preventing fatigue failure is by minimizing stress concentration due to improper design, metallurgical or manufacturing factors. The specific measures to be adopted for improving the spring life begin with the selection of clean steel, free of surface any defects or cracks. The leaf hole should be round and flat. Moreover, after heat treating the top corners of the major leaves must be trimmed into curved (rounded) form to further decrease the stress-raising action. This operation also eliminates partially the decarburized layer at the most critical region i.e. hole. Decarburization of the leaves during the manufacturing process must be prevented. Likewise, heat treating must be conducted so as to obtain a pure tempered martensite structure. Additional preventive measures to increasing the fatigue strength of the springs include improving the surface quality of the leaves as regards both raw material (steel sheets) and manufacturing process.

5. CONCLUSIONS

In this study, the efforts have been taken for a review on fabrication and testing procedure of leaf spring. The different techniques of testing have been discussed as well as the possible failures in the leaf spring are also discussed. It includes static test, fatigue test, Macroscopic Inspection, Chemical analysis and Metallographic Analysis. From this study it is found that the premature failure in the leaf springs by fracture of a leaf is due to mechanical fatigue caused by a combination of design, metallurgical and manufacturing deficiencies. Fatigue failure is started in the vicinity of the leaf central hole due to the effect of high stress concentration and in the direction normal to the acting tensile stress. The stress concentrators included the complex geometry of the hole, its sharp corners, notches caused by the bolt thread and various surface defects such as scabs and rolling lines in the starting sheets of unclean steel. The negative effects of all these factors are steel decarburization, during the manufacturing process, which results into to inadequate hardness in the springs and the local presence of soft products (ferrite) in the material structure.

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