Vol. XV & Issue No. 01 January - 2022
INDUSTRIAL ENGINEERING JOURNAL

INVESTIGATION OF FAILURE OF DOUBLE SUSPENSION SPRING OF RAILWAY COACH

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Abstract

Shock absorber spring is important component in fiat bogie of coach of Indian railways. Nested springs are used in double suspension system of fiat bogie. The most common problem of the failure of suspension system is the failure of springs during service. When a spring fails in a suspension system in a Fiat Bogie there are a number of mishaps which can happen like accidents, discomfort, loss of life these are some of the extreme happenings. The frequent failure of spring also results in valuable man hour wastage in maintenance and replacement of it. In this paper the causes responsible for the spring is studied and the failure analysis of it is presented. The study reveals major reasons of the failure of spring- failure due to reduction in the permissible free height, fretting, stress corrosion and rubbing marks. The study is carried out in the period of March 2019 and total 144 defects were reported. The paper also presents the metallurgical analysis of the bogie spring.

Keywords- fiat bogie, spring, failure analysis

INTRODUCTION

In today's age it is very important for a system to be more efficient and cost effective. The Failure of Spring in railways causes severe problems. When a spring fails in a suspension system in a LHB Fiat Bogie, there are a number of mishaps which can happen such as accidents, discomfort, loss of life these are some of the extreme happenings.The most common problem occurred in the fiat bogies is failure of nested spring used in the double suspension system. The central Railway Loco Workshop, Parel, Mumbai, carry out the maintenance and overhauling of the fiat bogies which are commissioned in India in 2001. Indian Railways has entered in a contract with M/s.LHB (Linke Hofmann Busch), Germany for supply of modern light weight high speed coaches. The coaches are of air-conditioned type chair car and generator car, which are fit for operation at speed of 160 kmph. Coaches shall have a speed potential of 200 kmph with suitable additions. The use of LHB Bogies have a lot of benefits which are: Higher carrying capacity, Better pay to tare ratio, low corrosion, low maintenance, LHB coaches have authentically superior interior with GRP panels for side wall and roof paneling. The bogie consists of two suspension system: Primary and Secondary suspension. Both the suspension systems contain two springs: Inner and Outer spring. The suspension system is the key system to absorb shocks and provide cushioning effects. LHB bogies are very efficient with the suspension system being one of the most important parts of the assembly. The suspension system is the principle element that transmits shocks from the shell of coach to the bogie and then to rails. These shocks generate due to the road irregularities. Expansion and compression of spring absorb the shock. These shocks sometimes cause the inner spring of the primary suspension system to fail.

The fatigue failure of the primary suspension (inner spring) takes place in a number of ways raw materials defects, surface imperfections, improper heat such as treatment (quenching cracks during manufacturing), corrosion, vibration effect and rubbing. This failure of spring leads to a lot of maintenance and time. In order to get a rough idea of the LHB bogie the Fiat bogie assembly is shown in fig 1.1 and 1.2.

Figure 1: Fiat Bogie Assembly

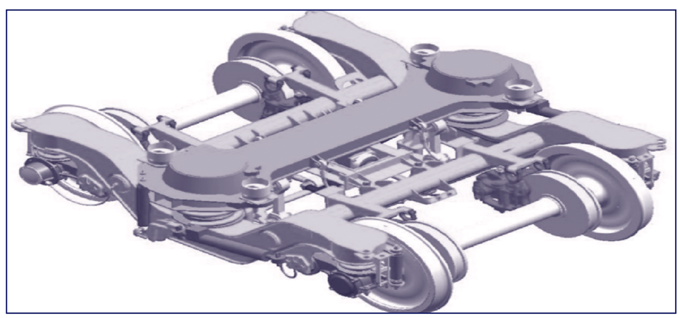
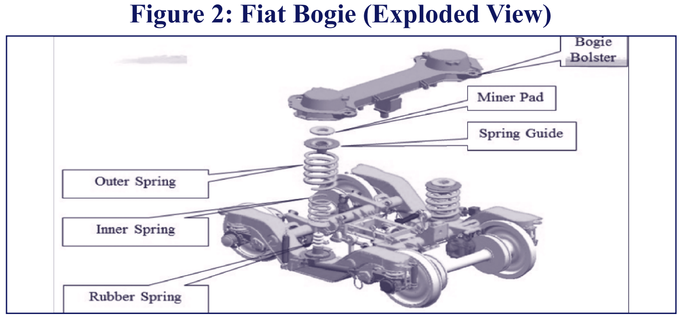


Figure 2: Fiat Bogie (Exploded View)



The trains often experience the frequent failure of springs. The actual life of spring is far less and is about 1 year. The spring life varies from train to train and largely depends on the quality and maintenance of it in the workshop. From the statistics collected from the maintenance workshop around 30 springs of non AC coaches failed in the year 2018 out of which 8 springs were from the trains running between Solapur to Kolhapur and Siddheshwar Express. The paper discusses the reasons of failure of springs and detailed metallurgical investigation of the same.

LITERATURE REVIEW

Youli Zhu et al. (2014) analyzed why a compression coil spring fractured at the transition position from the bearing coil to the first active coil in service, while the nominal stress here should always be much less than that at the inside coil position of a fully active coil. Visual observations indicated that a wear scar was formed on the first active coil and the fracture surface showed radiating ridges emanating from the wear scar. Scanning electron microscopy examination showed crescent shaped region and beach marks, typical of fatigue failure. Pastorcic, et.al. (2019) in their paper presented the result of failure and fatigue analysis of a coil spring removed of a personal vehicle after having failed in service. Failed coil was examined in order to determine the causes of the fracture using experimental procedures like visual observations, optical and SEM. Hardness test was performed and the chemical composition of the material was determined. After experimental analysis of the failed coil spring it can be noticed that the fracture surface is oriented at 45^0 to the wire centerline, typical of torsional fatigue failure under cyclic loading. Fracture on the surface of the wire started from formation of corrosion pits on it due to the protective paint layer damaged by the contact between two adjacent coils. It was concluded that final fracture was a result of continuous contact between the coils which formed corrosion pits that served as crack initiation points. Goran Vukelic , Marino Brcic (2016) have analysed the failure of coil spring in motor vehicles and predicted that Several factors, among them inherent material defect combined with material fatigue and helped by insufficient corrosion protection, caused failure of coil spring. In *Failure Investigation Report, CMT Laboratories, Parel (2018):* The failure investigation reports states that the fracture plane is inclined at 45 degree to the axis of the rod. They further specify that failure of spring has rubbing marks and corrosion marks near the fracture surface. In *Raut, S. P, et.al.,(2014)* research paper work the author present the comparison of various methodologies used by various authors and their application and limitations. Author discretizes the failure analysis in three different objectives of finding mode of failure, failure causes, root causes in which we specifically focus our scope of research on the failure causes and root causes. *Dalvi, S. D,et.al.,(2017) carried out* failure analysis of a fractured roller shaft of a pad steam machine that led to catastrophic consequences in terms of damage to other equipment, loss of production etc. Using standard procedure for failure analysis the author founds that due to stress concentration a micro-crack initiation took place at the weakest section and fracture of shaft took place. *Barella,et. al.,(2011) in their paper on* failure analysis of turbine blade, the author presents his views by discretizing the fracture zone as crack initiation , crack growth and final fracture. The author observes the fretting fatigue damage which caused the cracking of the component and the improper shot peening was the result of growth of crack. Hence author concludes that the failure of blade was primary due to improper service condition which caused the fretting fatigue and due to improper manufacturing conditions which lead to growth of crack. *Manoj A. Kumbhalkar,et.al.,(*2015) have conducted analysis the helical compression type of spring and revealed that the failure occurs due to design incompetency by increase of stresses at curvature and at maximum tractive efforts at various speed. *P.V.V. Kishore,et.al.,(2017)research work* describes the method train rolling stock examination in which visual examination was done by an individual of railway to keep visual observation of the parts of the train during motion. However, it is not possible to have visual observation with effectiveness because it is not possible to observe each part. Author uses a Single shape prior to power the level set function for object segmentation using a wide-angle high-speed camera to observe the parts and uses algorithms for segmenting defective parts with Non-defective shape priors by weigh vector adjustment. *Kumar,et.al.,(2013) have done* static analysis of primary suspension spring, the author uses two materials for comparing the stress value and deflection values. 60Si2MnA steel & Chrome Vanadium were used for research work and then using ansys 14 and analytical calculations author concludes that both the material have nearly same stress values but the deformation value is less for 60Si2MnA steel compared with Chrome Vanadium. *Pyttel,et. al.,(2014)* presented research paper which deals with the comparison of various spring material and their fatigue life. The author also studies about the shot peening conditions and experimented about the effect of double shot peening on the end coil failures ad found no change in the percentage of failure due to double shot peening in case of SiCr- and SiCrV. *Prawoto,et. al.,(2008) i*n their research work the authors compared the parameters affecting the performance of spring. The failures presented range from the very basic including insufficient load carrying capacity, raw material defects such as excessive inclusion levels, and manufacturing defects such as delayed quench cracking, to failures due to complex stress usage and chemically induced failure. Author describes all the possible defects that causes failure of the spring including inclusion and corrosion by modeling both as a FEM Model. Author also includes decarburization in his research work and considers as least weighted compared to all other defects. Also the author found that the values of residual stress induced on the surface due to shot peening are less for decarburized material hence he characterizes the shot peening as surface imperfection defect. *Joshi,et.al.,(2014),* studied the casting and the casting defects in various stages of the process. Using quality control techniques for finding out the remedies for the problem. The author uses cause effect diagram for listing the causes of specific failure reasons in the systematic way. The author also conducted Pareto analysis for identification of major defects those are contributing in major rejection percentage. Nehete et al. (2021), investigated the failure of spring in fiat bogies and have presented root cause analysis and reasons responsible for failure of it. Vukelic(2016)describes the failure of the spring was due to insufficient corrosion protection which leads to formation of corrosion pitting marks. Eryürek,(2007)works on the design optimization and the failure of spring were due to brittle fracture caused due to less fracture toughness.

Failure Investigation: The investigation is started first with collection of data for failure of spring over a fixed period of time. . The characteristics of various defects specifically raw material defect, manufacturing defect, improper service condition, environmental defects, surface imperfection etc. are considered in the study. So considering their way towards finding the cause of failure of spring as a primary step of research on the root cause finding on failure of spring is to have an actual visual inspection of the failure surface for effective observation the visual observation must be done immediately after the occurrence of failure. Visual inspection include all the possible observations seen during the inspection of the springs and noting the observation along with the comments about their appearance, nature, colour, any surface irregularity etc. seen near the surface of failure. The cause effect diagram and Pareto analysis is prepared for finding all the possible causes for failure and the finding which failure is contributing the maximum times. The collection of data for the Pareto analysis includes frequencies of number of springs that fail due to several reasons. Twenty seven 27 spring were observed which failed due to reductions in free height. 10 nos. of springs that were observed and was found that there is the removal of paint at some spots and these springs were observed immediately when bought from manufacturer to workshop. This means that there is mishandling during the shipment of springs from manufacturer.30 nos. of fractured springs were observed and out of the 30 number of fractured springs all springs were found to have corrosion mark and rubbing marks. 25 nos. of spring had paint removal on the bearing coil where facture took place.18 springs were found to have scratch marks on the outer surface of active coil. 3 number of spring had welding spatter marks and 1nos. (approx.) of spring were failed and not even replaced due to urgent requirement and this means that there is improper scheduling of maintenance. The table 1 shows the defect analysis carried out in March 2019. The parato diagram is prepared based on the table 1 as shown in figure 3. The cause and effect diagram is prepared considering the 6 major causes of defects which are the main branches, each having various root causes which form sub branches as shown in figure 4.

Table 1: Defect analysis (March 2019)

No.	Type of defects	Total number of defects	Defects percent
1	Corrosion	30	20.83
2	Rubbing Marks	30	20.83
3	Free length crossing limit	28	19.44
4	Removal of paint	25	17.36
5	Improper handling	18	12.5
6	Surface coating pre service	9	6.25
7	Welding spatter marks	3	2.08
8	Improper scheduling	1	0.60
	Total	144	

Figure 3: Pareto analysis for March 2019

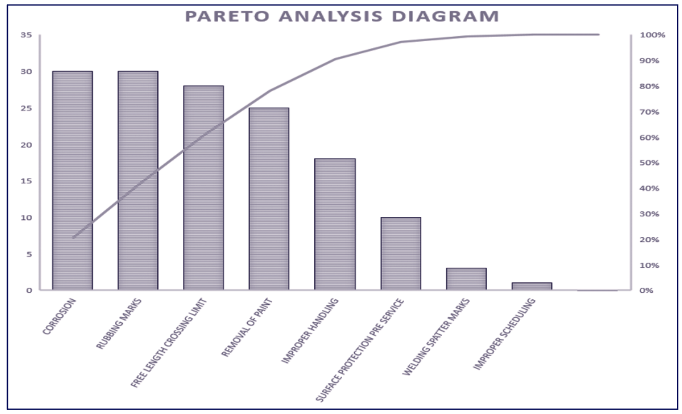
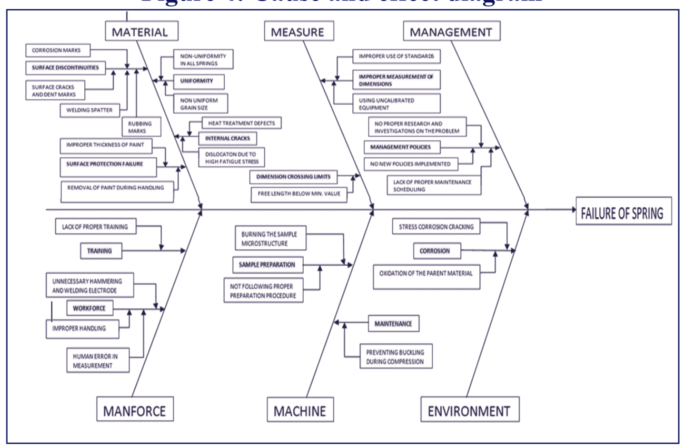


Figure 4: Cause and effect diagram



Further investigation is carried out for failure of springs and the following general steps are followed.

1. Collection of back ground information about failed components.
2. Preliminary examination of failed components.
3. Selection, preservation and cleaning of the sample.
4. Assessing the presence of discontinuity and defect in failed component by non-destructive testing.
5. Evaluation of the mechanical properties of the failed components.
6. Macroscopic observation of fracture surfaces.
7. Microscopic examination of fracture surfaces.
8. Metallographic examination of failed components.
9. Establishing the fracture mechanism.
10. Failure analysis using fracture mechanics approach.
11. Conducting test under simulated conditions if required.
12. Analysis of findings of investigation.
13. Report writing with recommendation.

Visual Examination Of Failed Components: Visual examination is the preliminary step in any failure analysis procedure. It is based on examination of defects which are visible to a human eye. The position of the failure and its condition after failing should be well recorded. This can be achieved by using detailed photographs.

Figure 5: Failed Primary Inner Spring of LHB Bogie Suspension

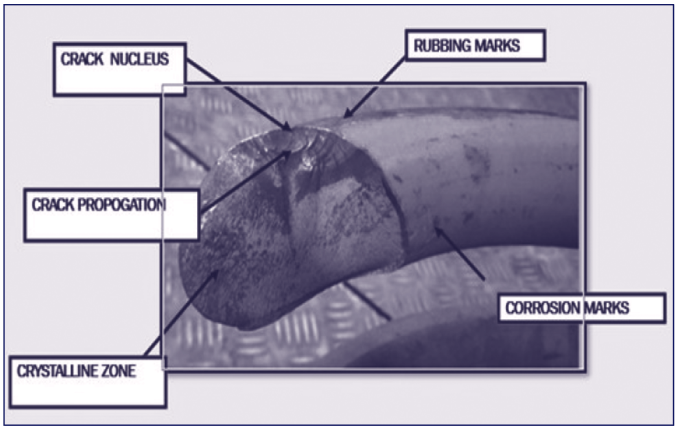
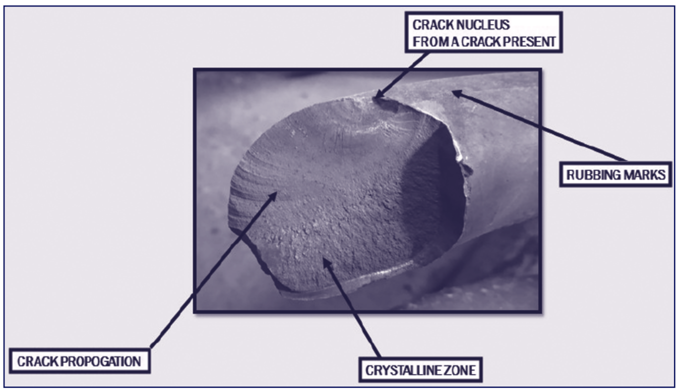


Figure 6: Failed Primary Inner Spring of LHB Bogie Suspension



In the above photograph figure 5 and 6, different factors found on the failed surface can be clearly seen. The failure of the inner spring has taken place in the first active coil of the spring. The failure is progressive and covers roughly 20-25% of the cross section area. The rest of the fracture region is observed to be crystalline in nature. Noticing further the crack nucleus is situated on the upper surface closer to the visible rubbing marks. The propagation of the crack can be vividly seen near the upper surface propagating towards the centre.

Composition Of Material Of Spring: The composition of the material is as follow.

Table 2: Spectrometer Result.

Sample no.	C	Mn	Si	Ch	V	Mo	S	Ph
FSP 17	0.49	0.89	0.27	1	0.13	0.18	0.011	0.004
FSP 21	0.49	1.04	0.30	1.02	0.12	0.016	0.009	0.005
FSP 24	0.47	0.86	0.21	0.96	0.10	0.17	0.009	0.005

Desired value by RDSO	C	Mn	Si	Ch	V	Mo	S	Ph
	0.48 - 0.56	0.70 - 1.10	0.40 (max)	0.90 -1.20	0.10 - 0.20	0.15 - 0.30	0.015 (max)	0.015 (max)

Selecting And Cleaning The Sample: The sample is collected from the area near the fracture zone or from area which was at a distance from the fracture surface, It was important to accurately select the correct region to consider and cut as a sample in order to identify and plot the sequence of events which would have contributed to the failure and the potential causes related to the failure. In the failed primary inner spring which was the component under investigation the sample was mostly collected from the area near the fracture surface so as to examine what exactly caused the spring to fail. Cleaning of the fractures sample was avoided as much as possible, this was important because cleaning removes the impurities and foreign substances present on the surface like oxide, paints, chemical, etc. which may be the reason behind the failure of the component.

Examining Discontinuities And Defects In Failed Component By Ndt: In order to determine the chance of the failure caused by the presence of few surface and surface imperfections, non-destructive testing (NDT) of fractured component especially near the fracture surface can carried out using variety of methods and techniques as per the requirement, Dye penetrant test (DPT), Magnetic particle test (MPT), Eddy current test (ECT), Ultrasonic test (UT), Radiographic test (RT) etc.

Destructive Test In Failure Analysis: Hardness test is the most common test conducted on a small fractured sample for evaluating heat treatment, this is followed by estimation of ultimate tensile strength and determination of the extent of work hardening or decarburization which has occurred on the fractured component during the service period, if there is any such proof. Since it is difficult to find large amount of material of the failed components for tensile and fatigue tests, failure analysts mostly rely on hardness tests. Hence it is for this reason that hardness test is conducted on the primary inner spring. The Rockwell hardness test results are shown in figure 7 and 8.

Figure 7: Hardness Test Results for a Primary Inner Spring A

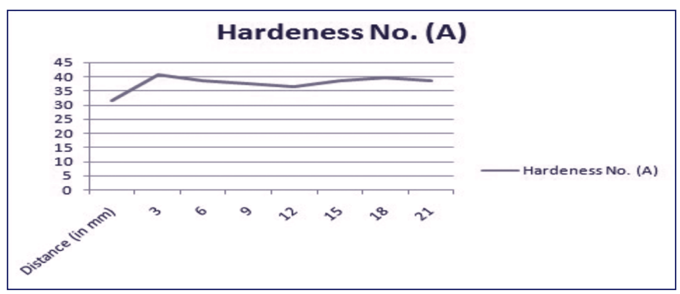
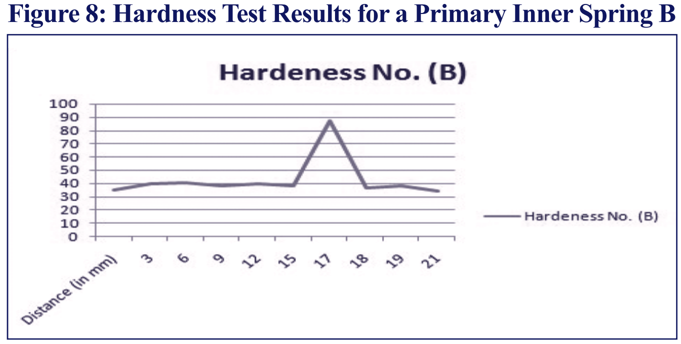
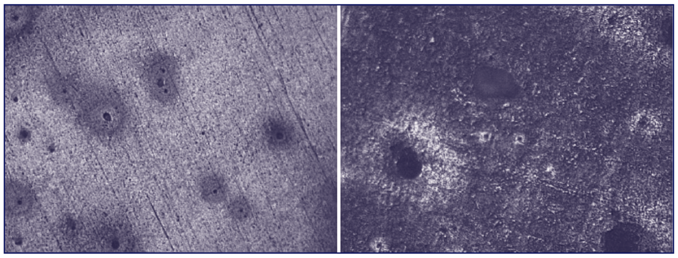


Figure 8: Hardness Test Results for a Primary Inner Spring B



Microscopic Examination Of Fracture Surfaces: The observation of spring microstructure shows (figure 9) the presence of pitting marks due to stress corrosion.

Figure 9: Spring Microstructure



Failure Analysis Using Fracture Mechanics Approach: In light of discontinuities if any found during investigation in failed component, fracture toughness & yield strength of material involved in failure, efforts should be made to analysis the situation using principle of fracture mechanics to establish that if presence of discontinuities in material have contributed to failure of the component under given service load conditions. The future study work can be made to relate the working condition and the crack also the crack propagation and the speed of crack opening.

Conducting Test Under Simulated Conditions: Analytic calculations were performed for finding out the contact stresses using Hertz Contact Stress Theory.

Total Load = Tane Weight + Bolster Weight + Bogie Weight + Passenger Weight + Bogie weight

Bogie weight = 6.7 tonnes, Bolster weight = 0.9 tonnes, Tane weight = 3.1 tonnes

Passenger weight = No. of seat + Passenger in lobby + Passenger in toilet + 20% safety margin

Total Passenger = 72 + 4 + 4= 80, Weight per passenger = 80 kg

Total Passenger weight = (80*80) + 20% safety margin = 7.68 tonnes

Total load = 6.7 + 0.9 + 3.1 + 7.68, Total load = 18.46 tonnes, No. of bogie for 1 coach = 2

Total no. of secondary spring in 1 bogie = 2 inner spring & 2 outer spring

Total no. of primary spring = 4 outer spring & 4 inner spring

Therefore, total no. of spring in 1 bogie = 12

Therefore, total no. of spring in 1 coach = 2*12 = 24 spring

Also, the load is equally divided on all spring (due to concentric spring) Load on one single spring (W) = 18.46 tonnes/24 spring = 0.7691 tonnes = 769.1 kg

Load on 1 single inner primary spring = 0.7691 tonnes

Contact Stress,

$$\sigma_{c\ max} = \frac{2*F}{\pi*b*L}\text{ , where F=W*9.81}$$

$$b = \sqrt{\frac{2*F}{\pi*L}\left[\frac{\frac{(1-\mu_1^2)}{E}+\frac{(1-\mu_2^2)}{E}}{\left(\frac{1}{D1}+\frac{1}{D2}\right)}\right]}$$

here, Material = 52CrMoV4 [EN1.7701]
E1 = E2 = Young's Modulus = 210*103 MPa, μ
|= Poisson's Ratio = 0.3, L = 10 mm

σ_{uc} = ultimate compressive strength=1600MPa
σ_{yc} = yield compressive strength=1400MPa

$$b = \sqrt{\frac{2*769.1*9.81}{\pi*10}\left[\frac{\frac{(1-0.3^2)}{210*10^3}+\frac{(1-0.3^2)}{210*10^3}}{\left(\frac{1}{27}+\frac{1}{27}\right)}\right]}$$

b = 0.239mm

$$\sigma_{c\ max} = \frac{2*769.1*9.81}{\pi*0.749*10}$$

$$\sigma_{c\ max} = 2045\ \text{MPa} < \sigma_{yc}$$

The Yield Compressive Strength is less than the induced contact stress hence the contact stress causes the fretting and rubbing action which reduces the fatigue strength of the material.

Analysis Of Findings Of Investigation: Analysis of all the information, facts, technical observations collected through the investigation is performed to establish the sequence of events that might have led to failure of a component. This can provide us an insight on few potential factors that have caused of failure of component.

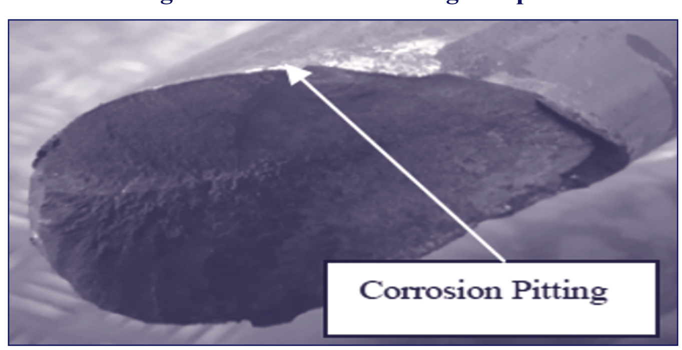
- The microstructural image reveals that the material is tempered marternsite. The microstructure was found with deep pitting marks.
- The broken springs were found with rubbing mark due to fretting,
- TZhe broken spring sample was found with rough and wavy surface
- Poor shot peening action on the inner surface due to less space issues can be the reason of less compressive stresses, because of which crack initiated starts propagating with speed and fractures the coil mostly from the inner surface of the spring coil,
- The new spring arrived from manufacturer was found with paint removal marks and the corrosion marks, removal of paint can be the reason for corrosion which causes Stress Corrosion Cracking.

RECOMMENDATIONS

Manufacturing recommendations:

The broken springs were found with rubbing mark due to fretting. Taking fretting into consideration, the spring base material must not come in contact with the water (moisture) or water particles or oxidizing environment.

Figure 10: Corrosion Pitting Sample



The broken spring sample was found with rough and wavy surface. These peaks and troughs can be the region for stress concentration and the crack initiation starts from the weakest portion, to avoid the fracture of spring due to improper surface finish, it is recommended to have proper surface finish which can increase the life of the spring.

The shot peening process must be done uniformly throughout the length on both inner and outer surface. Poor shot peening action on the inner surface due to less space issues can be the reason of less compressive stresses, because of which crack initiated starts propagating with speed and fractures the coil mostly from the inner surface of the spring coil.

The new spring arrived from manufacturer was found with paint removal marks and the corrosion marks. Hence removal of paint can be the reason for corrosion which causes Stress Corrosion Cracking. It is recommended to properly paint the springs and handle the spring properly during shipment so that the spring doesn't get damaged during the transportation. It is also recommended to use material handling devices to handling the spring during maintenance.

Figure 11: Paint removal sample

For avoiding the corrosion of springs, it is suggested to apply red oxide paint on the metal portion and then allow the red oxide paint to dry, after that the paint must be applied on new spring so that when paint is removed the base metal doesn't comes in direct contact with environment.

The paint on the springs was irregular and it is suggested to use spray pumps to paint the spring so as to maintain the uniform thickness of the paint throughout.

Design recommendations:

The design of the spring should be done taking the maximum no. of passenger travelling during peak hours and must be optimized by taking limiting space into consideration.

The design of spring must be updated taking new emerging material which deforms less on same loading condition must be commissioned so that the number of springs which failed due to reduction in free height will be reduced. Kumar,et.al.,(2013) uses two materials for comparing the stress value and deflection values. 60Si2MnA steel & Chrome Vanadium & concludes that both the material have nearly same stress values but the deformation value is less for 60Si2MnA steel compared with PAINT REMOVAL MARKS. Paint removal sample Chrome Vanadium. Hence using 60Si2MnA can reduce the rejection frequency of spring failed due to reduction in free height.

The free length of the coil must be increased so that the clearance between the coil is maintained after installation and fretting (rubbing) will be reduced which maintains the fatigue life of the component.

Maintenance Recommendations:

The maintenance of the bogie must be done by trained officials so as to make them aware of proper maintenance procedure which must be followed strictly.

The maintenance of any bogie part must be done free from water so as to avoid corrosion of the spring.

During every maintenance the spring must be checked for surface cracks and also fretting marks, if found with such must be maintained and not to be installed without fool proofing.

The spring must be handle safely above the ground surface and must not be rolled on the workspace as rolling of the spring causes surface scratches which can be the initiation of the crack.

The maintenance record from date of fitment to date of failure for each and every part of the bogie must be properly maintained so as to have clear calculation of the life of the part.

From the statistics collected from the maintenance workshop around 33 springs of non AC coaches failed in the year 2018 out of which 8 springs were from the trains running between Solapur to Kolhapur and Siddheshwar Exp. Therefore, the need arises to find out the root causes contributing to the failure of the spring, so it suggested to maintain the track terrain and also to clean the spring surface using dry air jet so as to avoid the pitting corrosion of the surface.

Before applying the paint on spring or any other part, the previous paint must be removed and after that cleaned using high pressure air jet instead of manual cleaning and be made dust free. After that red oxide paint must be applied and paint properly adheres to the metal surface avoiding metal to environment contact. red oxide is applied so as to avoid the contact of base metal and environment if paint is removed during service condition.

CONCLUSION

In this paper attempt has been made to investigate failure of spring of railway coach. As a part of it root cause analysis, Parato analysis and cause and effect diagrams are used to investigate the problems. Further detailed fracture analysis is carried out by visual observation and metallographic observation of sample. The study reveals the major findings such as the broken springs were found with rubbing mark due to fretting, the broken spring sample was found with rough and wavy surface, poor shot peening action on the inner surface due to less space issues can be the reason of less compressive stresses, because of which crack initiated starts propagating with speed and fractures the coil mostly from the inner surface of the spring coil, the new spring arrived from manufacturer was found with paint removal marks and the corrosion marks, removal of paint can be the reason for corrosion which causes stress corrosion cracking. The paper also recommended the precautions to be taken in manufacturing, designing and during maintenance.

Acknowledgment

Authors express gratitude Towards Shri. Rakesh Gupta (Chief Instructor-Basic Training Centre) and Shri. Vasant D. Meharkure (Dy. Chief Chemist and Metallurgist, Chemical Metallurgical Technology Laboratory, Parel) for their constant support and guidance.

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