



25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-0325

FAILURE ANALYSIS OF A COIL SPRING APPLIED IN THE REAR SUSPENSION OF A CITY VEHICLE

Gilmar Cordeiro Silva

Marcio Geraldo Magela Martins

Caio César Fernandes Silva

Felipe Maués Bergh

Pedro Henrique Rodrigues Paiva

Izabela Ângela Santos

Pontifícia Universidade Católica de Minas Gerais. 4580 Rio Comprido St, Cinco, Contagem, MG.

gilmarcord@gmail.com; mmartins@pucminas.br; cesarcaiofs@gmail.com; fbergh@gmail.com; pedrohpaiva@gmail.com;

izabelasantos72@gmail.com

Abstract. *Due to the presence of recurrent failures of coil springs in the rear suspension of a particular automotive vehicle model, a failure analysis was performed on one of the failed springs, in order to determine the root cause of the failure. To check if the material complied with the technical specifications of the design, chemical composition analysis, hardness tests and metallography were carried out. To reveal any possible surface defects, the spring went through the liquid penetrant test. Later, fractography was done via Scanning Electron Microscope (SEM), to identify all existent fracture mechanisms within the fracture surface. Based on the performed analyzes, it became possible to identify the root cause of the coil spring fracture, which was related to its manufacturing process. The results of this study can be used for further improvements in the design of this rear suspension spring.*

Keywords: *Coil Spring, Spring Steel, Failure analysis, Automotive Suspension, Fracture.*

1. INTRODUCTION

The suspension system is one of the most important elements in automotive design, being primarily responsible for linking the movement of the wheels to the body. It also acts to favor tire adhesion to the ground and to attenuate the oscillations caused by the contact between the wheels and ground unevenness (BARTOLOZZI; FRENDO, 2011). Coil springs are an important item in many types of suspension systems, used in front or rear sides of the chassis, whose function is to absorb the impact energy received by the wheels when in contact with irregular terrain, softening the oscillations transmitted to the car body (DE PAULA, 2013).

There has been extensive research on the topic of coil springs, since there is a trend in the automotive industry to reduce weight and increase performance of various components, including the aforementioned springs. Thus, it is necessary to understand the conditions in which the spring is bound to fail in order to avoid them and enhance the fatigue life of said spring. Prawoto et al. (2008) present a general overview of stress distribution and typical failure causes of coil springs. Both Kosec et al. (2015) and Vukelic & Brcic (2016) determined the cause of fracture of a coil spring via laboratory experiments. Similarly, Pastorcic et al. (2019) also investigated the root cause of failure of a coil spring, while also doing a numerical approach to quantify the reduction of fatigue life, which led the spring to fail under regular service loads.

Therefore, even though the methodology of failure analysis of coil springs has been developing, there is still room for future improvements and discussion of different root causes of those failures. This paper takes place in this context, aiming to determine the possible failure causes of a coil spring retrieved from the rear suspension of a city car. With the results of this research, it becomes possible to plan and execute corrective measures to ensure the reliability of the suspension system, making the vehicle safer and more pleasant to the driver.

2. METHODOLOGY

The failure analysis methodology applied in this study is similar to the one used by Pastorcic (2019), with the addition of metallography. All equipment and materials used in the development of this study belong to Fiat Chrysler Automobiles (FCA), located in Betim-MG.

The evaluation of a failed coil spring, retrieved from a torsion axle rear suspension of a city vehicle, started by gathering vehicle data, such as: vehicle model, engine type, vehicle identification number (VIN) and mileage traveled

before failure. Then, the visual inspection was conducted by capturing images of the failed part, showing the fracture location and the macroscopic features of the fracture surface.

Next, the liquid penetrant test was performed, using a Metal-Chek VP 30 liquid penetrant and a Metal-Chek D 70 developer. After the application of the developer, the visual inspection of the region was carried out, searching for any possible surface defects in the part.

The Rockwell C hardness test was conducted according to ASTM E18-15 and the equipment used was the Wilson® Rockwell® Series 2000 hardness tester. The Vickers hardness test was performed with a load of 30 kgf (HV30) on a Shimadzu HSV-20 hardness tester. The sample was prepared according to ASTM E3-95 and the test was conducted according to ASTM E384-16. Six measurements were performed for each hardness scale and the average values were considered.

The fractographic evaluation was performed in a FEI Quanta 250 scanning electron microscope (SEM). To observe the fracture surface in the equipment, the spring was cut transversely at a distance of approximately 30 mm from the fracture, in order to isolate the fracture from the rest of the spring. After cutting, the fracture surface was brushed and washed for the removal of impurities and oxides that could compromise the observation of fracture micromechanisms.

Finally, the chemical composition was determined by optical emission spectroscopy, performed with an AMETEK Spectromaxx spectrometer and the metallographic analysis was done with an Olympus BX60 optical microscope. The preparation of the samples for metallography consisted of cutting, mounting, grinding, polishing and etching with a solution of Nital 4% (nitric acid in a concentration of 4%). The cuts were made on a Setocom-50 Struers cutter, the mounting in a Struers CitoPress-30 mounting press, the grinding and polishing in a Struers Tegramin-30 polisher.

3. RESULTS AND DISCUSSION

In the visual assessment, the part was classified as a pigtail model spring, whose wire and coil diameters are gradually reduced at one end (in this case, the upper end). The fracture was located in the first active coil counted from the upper end, that is, in the region of smaller diameter of the spring wire. No damage was noted in the coating (anti-corrosion paint) that could indicate some kind of external impact or contact between coils during compression of the spring.

Both fracture surfaces generated from the spring failure were analyzed, being labeled as upper end fracture surface, attached to the fragment with smaller diameter (Figure 1A), and of the lower end, attached to the remaining coils of the spring (Figure 1B). In the fracture origin, complementary geometries were observed: the upper end surface presented a protrusion and the lower end surface, a groove.

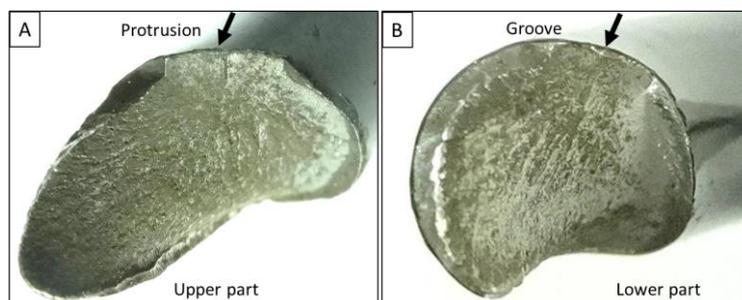


Figure 1. Fracture surfaces generated after the complete rupture of the coil spring.

From the defect found, ratchet marks were observed, indicating the initiation of a fatigue process. After the fatigue propagation zone, there were radial marks, which indicate fast crack propagation. The edges presented a sharp and shiny appearance, characteristic of the final fracture zone (shear lips).

The fatigue origin occurred in the upper region of the cross section of the spring wire, a fact that does not correspond to the region of higher active stresses, considering that the combined loads of torsion and bending should generate a peak combined stress in the inner part of the wire cross section (PRAWOTO, 2008). The fracture was completed in a plane located at approximately 45° with respect to the length of the spring wire, a typical characteristic of fractures caused primarily by torsion loads in materials with high hardness and low tenacity (brittle torsional fracture).

The penetrating liquid test evidenced the presence of surface marks (grooves) forming a helical pattern along the spring wire. Those defects detected in the test are possible stress raisers that may have reduced the fatigue life of the part.

Hardness tests were carried out in order to determine if the failed part met the technical specifications prescribed in the spring design. The failed spring met the hardness specifications on both Rockwell C and Vickers scales. It is worth mentioning that the hardness is an indirect indication of the mechanical strength of the material, therefore, it is considered that the mechanical properties of the spring concurred with the technical specifications of the design. Table

1 presents the average values of Rockwell C hardness (surface hardness) and Vickers hardness (core hardness) of the failed spring.

Table 1. Hardness values of the failed spring in Rockwell C and Vickers scales.

Scale	Failed Part	Design Specifications
Rockwell C	52,8 HRC	54±2 HRC
Vickers	647,3 HV30	645±6 HV30

The Scanning Electron Microscope (SEM) inspection showed a smooth surface with no fracture mechanisms in the fracture origin, indicating a lack of cohesion of the material before the fracture, that is, a manufacturing defect (Figures 2A and 2B).. Starting from the surface defect found, there was the development of ratchet marks, characteristic of fatigue (Figure 2B). The micromechanism found in the region was striation, also representative of fatigue. The defect was 1.44 mm wide and 0.16 mm deep, as shown in Fig. 2C.

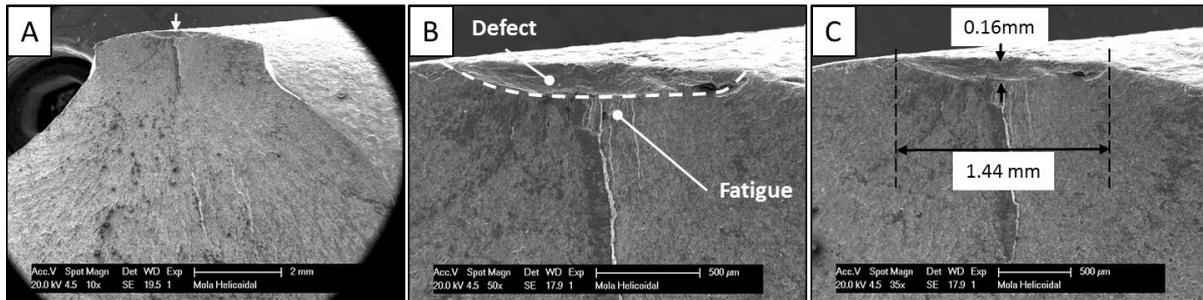


Figure 2. Fracture origin: (A) general view, (B) surface defect found at the fracture origin, (C) surface defect dimensions.

After the fatigue zone, a mixed mechanism of brittle intergranular fracture and dimples (microvoids) was observed, which is an evidence of an accelerated crack propagation in tempered steels with high hardness, such as the SAE 9254 steel alloy used in the coil spring (Figure 3).

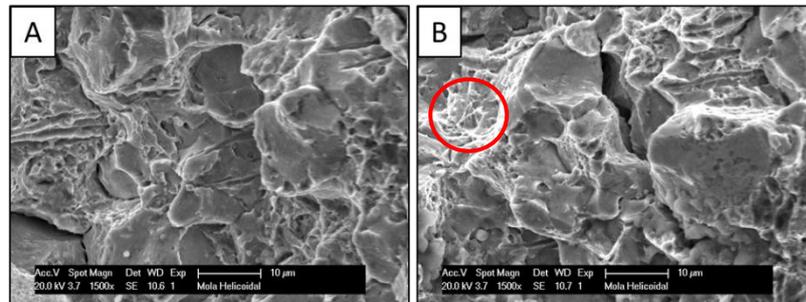


Figure 3. Mixed fracture mechanism of brittle intergranular and dimples.

The final fracture region (shear lips), present at the edges of the fracture surface, presented a mechanism formed essentially by elongated dimples. This morphology was expected due to the change in orientation of the principal stresses plane, which makes the final separation of the surfaces occur by shearing.

In Tab. 2 there is a comparison between the chemical composition specified in the Arcelor Mittal catalog (2018) and that obtained in the chemical characterization of the failed spring. From the weight percentage of the main elements present in the steel alloy SAE 9254, it could be seen that the material of the failed spring agrees with the chemical composition specifications prescribed for this spring.

Table 2. Chemical composition of SAE 9254 steel specified in Arcelor Mittal catalog and obtained from the failed spring.

	C	Si	Mn	P	S	Cr
Arcelor Mittal	0,51-0,59	1,3-1,6	0,6-0,8	0,03 max	0,03 max	0,6-0,8
Failed Spring	0,516	1,410	0,686	0,010	0,004	0,669

In the metallographic assessment, a martensite microstructure was identified in the spring core, as prescribed in the coil spring design (Figure 4A). The fracture origin was cross-sectioned, where the presence of partial decarburization was identified up to a depth of 0.09 mm (Figure 4B). This evidence indicates that there was an unacceptable material defect at the fracture origin. Cross-sections were also made in the surface marks, which formed a helical pattern along the spring wire, and, similarly, partial decarburization was found inside these defects. Those features, both at the beginning of the fracture and inside the superficial defects, suggest that the fracture started at one of these defects. In addition, the existence of decarburization within these defects indicates that they were already present in the part prior to the heat treatment.

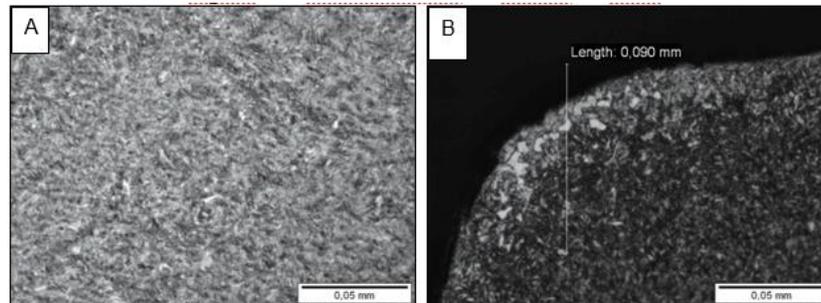


Figure 4. Coil spring metallography: (A) core and (B) fracture origin

4. CONCLUSIONS

With the aid of the failure analysis techniques applied in the present study, it was possible to determine that the helical spring fracture occurred due to fatigue under predominantly torsional loads. Fatigue life of the part was compromised by the presence of a surface defect (groove), which generated a stress raiser, increasing the magnitude of the alternated stresses acting on the spring during the regular use of the vehicle. Thus, the actual stresses acting on the coil spring exceeded those foreseen in its design.

The material in which the spring was manufactured was in accordance with the design specifications with respect to microstructure, hardness and chemical composition. Therefore, it was confirmed that the raw material used in the failed helical spring was a SAE 9254 steel alloy, quenched and tempered.

No evidence of irregularity was found in the setting of the spring in the lower or upper plates, or of excessive movement or displacement of the spring in its seat. There were also no impact marks or damage to the protective coating (anti-corrosion paint) that indicated poor use of the car. Therefore, the failure mode studied here could not be related to anomalies in the assembly process and/or negligence of the driver in vehicle care.

After gathering the aforementioned evidence, it was possible to backtrack on the origin of the defect, the radial forging process used to reduce the diameter of one end of the spring wire. There was a fracture in one of the forging hammers, which left the helical pattern marks, found only in the region of diameter reduction. The determination of the root cause associated with the radial forging process can then be used as a foundation to guide improvements in the manufacturing process, which can reduce the incidence of this failure mode.

5. ACKNOWLEDGEMENTS

The authors are grateful to the Pontifical Catholic University of Minas Gerais (PUC-MG) and to Fiat Chrysler Automobiles for technical support.

6. REFERENCES

- ARCELOR MITTAL. Aços longos - Aço Am54A. Belo Horizonte, 2018. 14 Set. 2018 <<http://longos.arcelormittal.com/produtos/catalogos/aco-am54a>>.
- ASTM E3-95. Standard Practice for Preparation of Metallographic Specimens. AMERICAN SOCIETY FOR TESTING AND MATERIALS, 1995.
- ASTM E18-15. Standard Test Methods for Rockwell Hardness of Metallic Materials. AMERICAN SOCIETY FOR TESTING AND MATERIALS, 2015.
- ASTM E384-16. Standard Test Method for Microindentation Hardness of Materials. AMERICAN SOCIETY FOR TESTING AND MATERIALS, 2016.
- Bartolozzi, R; Frendo, F. Stiffness and strength aspects in the design of automotive coil springs for McPherson front suspensions: a case study. Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering 225, p. 1377-1391, 2011.

- De Paula, R. F. V., 2013. Fadiga de Molas Helicoidais de Suspensão de Automóveis. Dissertação (Mestrado) – Universidade Estadual Paulista.
- Kosec, L; Nagode, A; Kosec, G; Kovacevic, D; Karpe, B; Zorc, B; Kosec, B. Failure analysis of a motor-car coil spring. Case Studies in Engineering Failure Analysis 4 (2015) 100–103.
- Pastorcic, D; Vukelic, G; Bozic, Z. Coil spring failure and fatigue analysis. Engineering Failure Analysis 99, p. 310–318, 2019.
- Prawoto, Y; Ikeda, M; Manville, S.K; Nishikawa, A. Design and failure modes of automotive suspension springs Engineering Failure Analysis 15, p. 1155–1174, 2008.
- Vukelic, G; Brcic, M. Failure analysis of a motor vehicle coil spring. Procedia Structural Integrity 2, p. 2944-2950, 2016.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.