THE ANALYSIS OF SUSPENSION SPRING DURABILITY IN PASSENGER CARS AFTER LONG-TERM OPERATION

[1] Zbigniew BAŁAGA, [1] Michał OPYDO, [1] Agata DUDEK

[1]*Czestochowa University of Technology, Czestochowa, Poland, EU, zbigniew.balaga@pcz.pl*

https://doi.org/10.37904/metal.2025.5118

Abstract

This paper presents the results of a failure analysis of a suspension spring from a passenger vehicle, with a focus on the impact of long-term operation under real road conditions. The investigated spring, originating from a 2008 Peugeot vehicle, failed after 14 years of service and approximately 225,000 km of mileage. The objective of the study was to evaluate the durability of the spring material in the context of fatigue and corrosion-related degradation mechanisms. A comprehensive set of analyses was performed, including spectroscopic chemical composition analysis, hardness testing, microstructural observations, X-ray diffraction (XRD), and fractographic examination using scanning electron microscopy (SEM). The results showed that the spring was made of high-carbon steel with a composition close to 60SiCr7, exhibiting a tempered martensitic structure. The presence of manganese sulphide inclusions, localized corrosion products, and areas of brittle fracture morphology indicated the co-occurrence of fatigue and stress corrosion mechanisms. The findings highlight the role of both microstructural features and environmental exposure—particularly to chlorides from de-icing salts—in the progressive degradation of suspension components. This case study underscores the importance of considering combined mechanical and environmental stressors in durability assessments of automotive springs.

Keywords: Suspension spring, fatigue failure, stress corrosion, Vickers hardness, microstructure

1. INTRODUCTION

Suspension springs play a key role in a vehicle's running gear by storing and releasing mechanical energy in response to road surface irregularities and dynamic load changes. Their proper operation has a direct impact on the vehicle's traction properties, directional stability, ride comfort, and, above all, the safety of all road users during operation [1]. For this reason, the design and material selection for spring manufacturing are subject to strict requirements specified in standards such as PN-EN 10089:2005 and PN-EN 10270-2:2011.

One of the commonly used materials for spring production is 60SiCr7 steel, classified as a silicon-chromium alloy steel with high hardenability, intended for use under high dynamic loads. This material exhibits a high fatigue limit and a post-hardening hardness of up to 52 HRC, which ensures long-term dimensional stability and elasticity. This steel, along with other chromium-silicon steels, also meets corrosion resistance requirements. Alternatively, steels such as 50CrV4 and 60SiMn5 are also used, depending on mechanical demands and economic considerations. For all these materials, compliance with standards concerning chemical composition, microstructure, and mechanical properties is essential. Steels used in spring production are typically oil-quenched and tempered to obtain a uniform microstructure and appropriate mechanical properties. To improve fatigue resistance, springs are often subjected to shot peening, a process that induces beneficial compressive stresses on the material surface. The literature describes methods for extending the failure-free service life of suspension springs. In addition to shot peening, approaches involving diagnostic techniques based on artificial intelligence, chemical composition modifications, and protective coatings [2,3] are being explored. These measures are particularly important considering the increasing mass of modern vehicles, including both passenger and commercial types [4,5]. Despite the use of high-quality steels and precise heat treatment, springs may still suffer from operational damage, particularly due to material fatigue under repeated cyclic loading. Such damage often initiates in areas with elevated stress concentrations. The service life of suspension springs may also be shortened by material or manufacturing defects such as structural inhomogeneity, the morphology of non-metallic inclusions, improper heat treatment, or microcracks formed during the production process [2].

Environmental factors also play a significant role in spring degradation. Exposure to moisture, acid rain, and road salt used in winter maintenance can accelerate corrosion processes, adversely affecting the steel structure [6].

The advanced analysis [7] of damage to the suspension spring made of conventional steel presented in the article has significant implications for many other fields [8]. Understanding the mechanisms of fatigue and stress in road conditions is crucial not only from the point of view of vehicle component durability [9], but also in the context of optimizing [10,11] by reducing failure rates and extending the service life of parts. Alternative methods of producing springs or reinforcing them, such as [12] protective coatings or advanced forging [13] techniques, can significantly affect their resistance to degradation. Precision surface treatment, including the potential use of laser machining [14-16] to modify the surface layer, can also contribute to improving fatigue properties. Ensuring high quality [17] of manufactured springs requires not only rigorous standards, but also advanced methods of statistical analysis [18] of data from operational tests, which allows for better prediction of their durability and optimization of the design.

2. MATERIAL AND METHODS

A suspension spring from a passenger car, which had failed after prolonged service, was used for the study. The chemical composition of the steel was analysed using a Bruker spark spectrometer, and the obtained elemental contents are presented in **Table 1**. The measured chemical composition is like that of the spring steel grade 60SiCr7; however, a lower silicon content and a higher chromium content were observed compared to the values specified in the standard. A comparison of the measured composition with the standard specification for 60SiCr7 steel is also provided in **Table 1**.

To determine the structure of the tested steel, X-ray diffraction (XRD) analysis was performed using a SEIFERT diffractometer equipped with a cobalt anode tube. The resulting diffractogram revealed three diffraction peaks corresponding to martensite (**Figure 1**).

Table 1 Chemical composition of the steel used for the spring

Element	Average content (wt%)	Chemical composition of 60SiCr7 steel according to EN 10089 (wt%)
C	0.61	0.57 – 0.65
Si	1.34	1.60 – 2.00
Mn	0.73	0.70 – 1.00
Cr	0.68	0.20 – 0.45
P	0.01	≤ 0.025
S	0.02	≤ 0.025
Fe	bal.	bal.

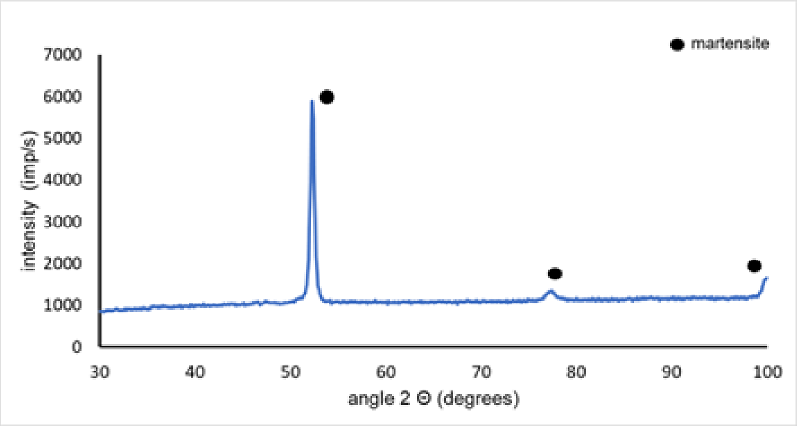

Figure 1 X-ray diffraction pattern obtained from the steel sample taken from the tested spring

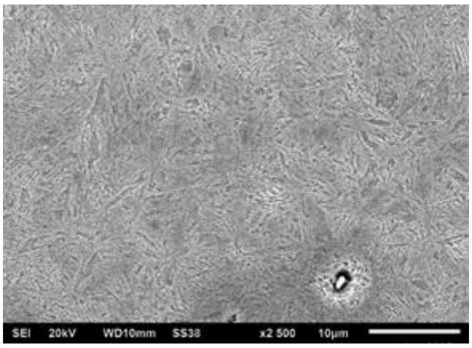

Figure 2 Microstructure of the steel being analysed by use of EDS

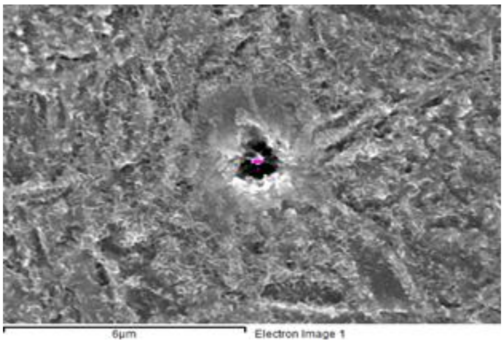

Figure 3 EDS analysis of a typical precipitate detected in the microstructure

Table 2 EDS analysis of a typical precipitate detected in the microstructure in **Figure 3**

Element	**Content (wt%)**
Si	0.95
S	5.85
Cr	0.89
Mn	9.95
Fe	82.36

Microstructural observations, fracture surface analysis at the failure site, and chemical composition analysis were performed using a JEOL JSM-6610LV scanning electron microscope equipped with an Oxford Instruments energy-dispersive X-ray spectroscopy (EDS) detector. The observations confirmed the results of the X-ray diffraction analysis and revealed that the tested spring exhibits a tempered martensitic structure, as shown in **Figure 2**. In the microstructure, precipitates were also observed, which, based on local chemical analysis, were identified primarily as manganese sulphides. An example of the chemical composition of such a precipitate presented in **Figure 3** shows **Table 2.**

Fractographic observations at the failure site of the spring revealed a brittle fracture with numerous visible microcracks. Representative micrographs are shown in **Figure 4**. Additionally, localized areas with distinct surface morphology were observed, with selected examples presented in **Figure 5**. Chemical composition analysis **(Table 3)** of these micro-areas revealed the presence of elements such as sodium and chlorine, suggesting the possible presence of chemical residues that may have accelerated the degradation processes in the steel. These compounds likely originate from de-icing road salts commonly used during winter to melt ice and snow.

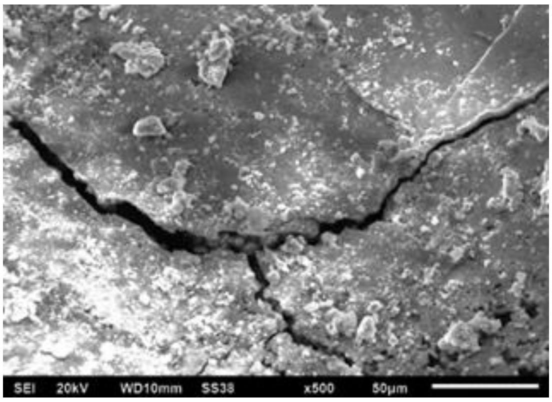

Figure 4 Representative microcracks in the steel on the fracture surface of the spring

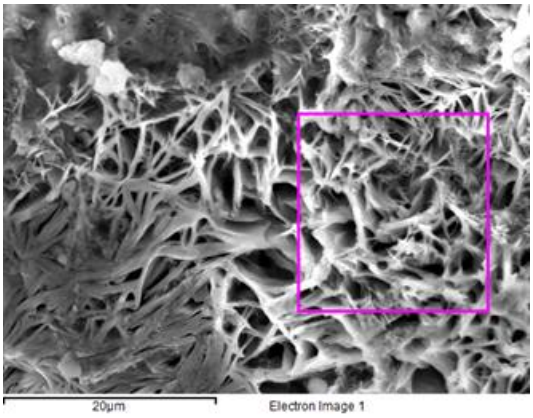

Figure 5 The fracture surface in the failure site of the spring

Table 3 Chemical composition analysis of the deposit on the fracture surface in the failure site of the spring (**Figure 5**)

Element	**Content (wt%)**
C K	19.31
O K	45.21
Na K	3.39
Mg K	0.18
Al K	1.04
Si K	2.03
S K	0.27
Cl K	2.54
Ca K	0.71
Fe K	25.32

The presence of silicon and iron corresponds to the chemical composition of the spring steel, while the detection of oxygen may indicate corrosion processes and the formation of iron oxides in the affected regions. Furthermore, the identified silicon may also originate from residual silica (sand), which is frequently present on road surfaces as a mechanical contaminant.

To estimate the hardness of the tested spring, Vickers hardness measurements were performed using a 10 kgf load (HV10). The average hardness obtained from the measurements was 549±24 HV10.

3. CONCLUSION

This study presents the results of an analysis of a passenger car suspension spring that failed after many years of service under typical Central European roads and climate conditions. The geographic operating environment may have significantly influenced the component's durability due to the region’s variable climate

– characterized by hot summers, rainy transitional seasons (spring and autumn), and cold winters with road surfaces covered in slush, ice, and de-icing salts.

The objective of the study was to identify the failure mechanism of the spring and determine the factors that may have initiated and accelerated damage, particularly in the form of fatigue-corrosion cracking. Spectroscopic chemical analysis revealed that the component was made of high-carbon steel, with a composition closely resembling the 60SiCr7 spring steel grade, as defined in the PN-EN 10089 standard for heat-treated steels. Some deviations from the nominal composition were observed, particularly in the silicon and chromium content. Microstructural observations and X-ray diffraction analysis confirmed the presence of tempered martensite, which is typical for spring steels subjected to hardening and tempering.

The microstructure also revealed unevenly distributed precipitates, identified through EDS analysis as manganese sulphides. Although the total sulphur content remained within the permissible limits of the standard, the presence of these inclusions could have promoted local stress concentrations and acted as initiation sites for microcracks under cyclic loading. This is particularly critical for components such as suspension springs, which are exposed to long-term dynamic stresses.

The average Vickers hardness was measured at 549 HV10, which falls within the expected range for heat-treated spring steels. However, such a high hardness, while beneficial in terms of wear resistance, may reduce the material's ability to absorb energy – especially in the presence of microstructural defects or inclusions with lower mechanical strength.

Fractographic analysis using a scanning electron microscope revealed a brittle fracture morphology, with numerous microcracks and areas exhibiting a porous, sponge-like surface structure. In these zones, elements such as sodium, chlorine, and oxygen were detected in addition to typical steel components such as iron and silicon. This chemical composition indicates active corrosion processes, with iron oxides and chloride-containing residues likely originating from road salt used during winter maintenance. The combination of aggressive environmental exposure and cyclic mechanical loading suggests that stress corrosion cracking may have played a role in the failure process.

In conclusion, the failure of the analysed spring resulted from a complex interaction of factors: prolonged operation under variable loading, the presence of microstructural imperfections (e.g., MnS inclusions), high material hardness limiting energy absorption, and exposure to a corrosive environment. These findings highlight the importance of considering both material properties and environmental conditions when assessing the durability of suspension springs in vehicles operating under temperate climate conditions.

REFERENCES

[1] PUTRA, T.E., HUSAINI, IKBAL, M. Automotive suspension component behaviors driven on flat and rough road surfaces. *Heliyon*. 2021, vol.7, art. e07528. https://doi.org/10.1016/j.heliyon.2021.e07528

[2] YAR, M.A., WANG, Y., ZHOU, X., SOUTIS, C. Corrosion behaviour of an industrial shot-peened and coated automotive spring steel AISI 9254. *Corrosion Engineering, Science and Technology.* 2018, vol. 53, pp. 564-573. https://doi.org/10.1080/1478422X.2018.1511328

[3] VUKELIC, G., BRCIC, M. Failure analysis of a motor vehicle coil spring. *Procedia Structural Integrity.* 2016, vol. 2, pp. 2944-2950. https://doi.org/10.1016/j.prostr.2016.06.368

[4] REMALLI, N., HASAN, M., KISHORE, K.N., RAJAVEL, G., MÜNCH, M., SAMBANDAM, M., RAJULAPATI, K.V BRANDT. Pivotal role of retained austenite as a low temperature creep controlling mechanism in a martensitic spring steel. *Materials Science & Engineering A*. 2023, vol. 887, art.145751. https://doi.org/10.1016/j.msea.2023.145751

[5] LIU, Y., WEN, Z., WU, X., PENG, B., ZHOU, Y., TAO, G. Investigation of fatigue durability and influencing factors of coil springs: A case study for metro vehicles. *International Journal of Fatigue*. 2024, vol.187, art.108469. https://doi.org/10.1016/j.ijfatigue.2024.108469

[6] ATKINSON, C., NAVEED, N., Ul HAQ, M., MEHRABI, H., A. High Cyclic Fatigue Behavior of Varied Pitch Compression Springs for Automotive Applications. *Journal of Robotics and Mechanical Engineering*. 2022, vol. 1. https://doi.org/10.53996/2770-4122.jrme.1000108

[7] PIETRASZEK, J., SKRZYPCZAK-PIETRASZEK, E. The Optimization of the Technological Process with the Fuzzy Regression. *Adv. Mater. Res*. 2014, vol. 874, 151-155. https://doi.org/10.4028/www.scientific.net/AMR.874.151

[8] KLIMECKA-TATAR, D., RADOMSKA, K., PAWLOWSKA, G. Corrosion resistance, roughness and structure of Co64Cr28Mo5(Fe, Si, Al, Be)3 and Co63Cr29Mo6.5(C, Si, Fe, Mn)1.5 biomedical alloys. *Journal of the Balkan Tribological Association*. 2015, vol. 21, 204-210.

[9] KLIMECKA-TATAR, D., PAWLOWSKA, G., ORLICKI, R., ZAIKOV, G. Corrosion Characteristics in Acid, Alkaline and the Ringer Solution of $Fe_{68}Co_xZr_{10}Mo_5W_2B_{15}$ Metallic Glasses. *Journal of the Balkan Tribological Association.* 2014, vol. 20, 124-130.

[10] ORMAN, L., RADEK, N., PIETRASZEK, J., SZCZEPANIAK, M. Analysis of Enhanced Pool Boiling Heat Transfer on Laser-Textured Surfaces. *Energies*. 2020, vol.13, art. 2700. https://doi.org/10.3390/en13112700

[11] ORMAN, Ł., MAJEWSKI, G., RADEK, N., PIETRASZEK, J. Analysis of Thermal Comfort in Intelligent and Traditional Buildings. *Energies*. 2022, vol.15, art. 6522. https://doi.org/10.3390/en15186522

[12] RADEK, N., PIETRASZEK, J., GADEK-MOSZCZAK, A., ORMAN, L., SZCZOTOK, A. The Morphology and Mechanical Properties of ESD Coatings before and after Laser Beam Machining. *Materials*. 2020, vol. 13, art. 2331. https://doi.org/10.3390/ma13102331

[13] JONSTA, P., JONSTA, Z., BROZOVA, S., INGALDI, M., PIETRASZEK, J., KLIMECKA-TATAR, D. The Effect of Rare Earth Metals Alloying on the Internal Quality of Industrially Produced Heavy Steel Forgings. *Materials*. 2021, vol. 14, art. 5160. https://doi.org/10.3390/ma14185160

[14] RADEK, N., KONSTANTY, J., PIETRASZEK, J., ORMAN, L., SZCZEPANIAK, M., PRZESTACKI, D. The Effect of Laser Beam Processing on the Properties of WC-Co Coatings Deposited on Steel. *Materials*. 2021, vol. 14, art. 538. https://doi.org/10.3390/ma14030538

[15] RADEK N., T. Influence of laser texturing on tribological properties of DLC coatings. *Prod. Eng. Arch*. 2021, vol. 27, 119-123. https://doi.org/10.30657/pea.2021.27.15

[16] ORMAN, L., RADEK, N., PIETRASZEK, J., WOJTKOWIAK, J., SZCZEPANIAK, M. Laser Treatment of Surfaces for Pool Boiling Heat Transfer Enhancement. *Materials*. 2023, vol.16, art. 1365. https://doi.org/10.3390/ma16041365

[17] CZERWIŃSKA, K., PIWOWARCZYK, A. The use of combined quality management instruments to analyze the causes of non-conformities in the castings of the cover of the rail vehicle bearing housing. *Prod. Eng. Arch*. 2022, vol. 28, 289-294. https://doi.org/10.30657/pea.2022.28.36

[18] PIETRASZEK, J., GOROSHKO, A. The Heuristic Approach to the Selection of Experimental Design, Model and Valid Pre-Processing Transformation of DoE Outcome. *Adv. Mater. Res*. 2014, vol. 874, 145-149. https://doi.org/10.4028/www.scientific.net/AMR.874.145