Engineering Solid Mechanics 12 (2024) 33-40

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Prototype production and investigation of mechanical properties of leaf springs used in air suspension systems

Dilşad Akgümüş Gök[a*]

[a]*Department of Mechanical Engineering, Istanbul Aydin University, Istanbul, 34295, Turkey*

A R T I C L E I N F O

Article history:
Received 21 May 2023
Accepted 24 July 2023
Available online
24 July 2023

Keywords:
Leaf springs
Suspension systems
Mechanical properties

A B S T R A C T

Leaf springs are machine elements that provide safety and driving comfort by storing the energy caused by the loads coming to the chassis and transport elements depending on the road conditions. Leaf springs are suspension elements commonly used particularly in heavy commercial vehicles. In this study, prototype leaf spring production was realized by forming the metal sheet and making heat treatments. Residual stress analysis, hardness, bending and strain gauge measurements were performed to examine the mechanical properties of the leaf spring produced. After the applied tempering process, the leaf spring microstructure was examined.

1. Introduction

Suspension systems dampen the shock from the road by converting them into vibration, prevent skidding during the vehicle maneuver. It increases the friction rate in the tires and increases the vehicle's handling capacity. Suspension systems are located between the wheel and the chassis. The systemic functions of the suspension systems work together with the tires while driving to soften the loads, oscillations and sudden shocks transmitted from the road to the tire. The functions of the suspension system parts, on the other hand, carry the load and store the sudden load coming from the tire, preventing the impulses from the road to be transferred directly to the chassis.

Air suspension systems are higher comfort systems preferred in commercial vehicles, buses, trucks and luxury passenger cars. As the use of air suspension systems improves driving comfort, dynamic behavior and height settings, the control systems of air vibration dampers become increasingly important in modern chassis, seat and cabin applications. Air suspension systems are the most preferred suspension systems in commercial vehicles with high comfort expectations. Its main principle is to use the air it compresses in a closed volume as a spring and to achieve a more comfortable ride by using the high elastic behavior of the air trapped in the rubber.

Leaf springs have been fundamental components of automotive suspension systems since the early days of the automotive industry. They function similarly to other springs, absorbing and storing energy to be released when the load is removed. The manufacturing methods employed play a crucial role in producing durable and long-lasting leaf springs. Particularly in heavy commercial vehicles, the characteristics of leaf springs significantly impact vehicle behavior under diverse conditions and necessitate appropriate controls (Hao et al., 2013; Savaidis et al., 2013). In modern times, computer-aided design and analysis programs facilitate studies aimed at enhancing leaf spring efficiency. Various types of suspension elements are used depending on the vehicle type. Passenger cars commonly utilize helical springs, while commercial vehicles prefer parabolic or air leaf

* Corresponding author.
E-mail addresses: dilsadakgumus@aydin.edu.tr (D. A. Gök)

ISSN 2291-8752 (Online) - ISSN 2291-8744 (Print)

doi: 10.5267/j.esm.2023.7.004

springs. The selection and production of parabolic leaf springs are critical for ensuring expected performance and longevity (Scuracchio et al., 2013; Gandhi et al., 2014). To achieve this, accurately determining the behavior and loading conditions of the spring suspension system is essential. Leaf springs are typically crafted from flat steel, formed into a tape-like shape and stacked from top to bottom. These layers are bound together at the center using a center bolt or rivet and are clamped to prevent sliding. This attachment method ensures that the spring remains intact and maintains its bending properties.

In the literature, researchers have adopted various approaches to address leaf spring-related challenges. For example, they have explored designing, manufacturing, and analyzing composite springs for small cars, involving the development of single-leaf glass-fiber reinforced plastic springs with varying thicknesses, similar to multi-leaf steel springs (Al-Qureshi, 2001). Additionally, investigations have been carried out on the residue from the shot peening process, with a focus on stress distribution and Almen density. The ultimate aim was to optimize the shot peening process to enhance the fatigue life of leaf springs (Atig et al., 2018). Moreover, there have been studies on manufacturing single parabolic leaf springs for heavy trucks, with an emphasis on weight reduction to achieve cost savings and improved fuel consumption (Tokgönül et al., 2018). In the literature, researchers have also investigated the effect of adding copper to powder metal steel parts. This involved applying high temperature and shot peening processes and testing fatigue life, comparing the results using S-N curves (Başaran et al., 2007). Furthermore, extensive research has been conducted on the mechanical properties and characterization of composite materials used in leaf springs. The evaluation of EN45 steel and composite-based leaf springs has revealed properties such as low density, low weight, high strength, and the positive impact of increasing weight fraction and dimensions on strength and hardness (Singh et al., 2018). Characterization and investigation of the mechanical properties of composite material leaf springs have been conducted as well. Researchers have utilized a hand lay-up fabrication technique with epoxy resin, hardener, and E Glass fiber as composite materials. Material properties such as hardness and bending behavior were examined (Ganesh et al., 2020). Another area of study involved the design of a Z type parabolic leaf spring, accompanied by the development of a finite element model. Shape and stress analyses were performed using finite element analysis to identify high-tension regions in the leaf spring and select an appropriate design to enhance its performance. In addition, fatigue life was determined through the N-Code program, and physical tests were conducted to validate the findings (Akgümüş Gök & Baltacı, 2023). In summary, these studies demonstrate the ongoing efforts to improve leaf spring design and materials, especially in commercial vehicles, to enhance performance, durability, and overall efficiency. The use of computer-aided design and analysis tools has been instrumental in advancing research in this area.

This paper deals with production, mechanical properties and microstructure analysis of Z type leaf spring. In this study, the production process of this leaf spring and its heat treatments are explained in detail. Afterward, residual stresses of the leaf spring produced as a result of heat treatments and shot peening were measured by X-ray diffraction. Microhardness and bending test were carried out by the standard for the leaf spring. Stress measurements were made with strain gauges in certain parts of the leaf spring. Finally, the microstructure images and grain sizes of the tempered leaf spring were examined.

2. Material and Method

2.1. Material

The present research work concentrates on the progress of the field of automobile industry. 52CrMoV4 spring steel was preferred in this study due to its use especially in leaf springs and other vehicle springs, being exposed to very high stresses, and suitable for quenching and annealing heat treatments. Z type leaf spring prototype produced from this spring steel was created and mechanical properties of this leaf spring were analyzed. Reference treatment for 52CrMoV4 DIN 17221 is quenched from 860°C followed by tempering at 450°C. The chemical composition of this spring steel is given in Table 1.

Table 1. Chemical composition

C	Si	Mn	P	S	Cr	Mo	V	Cu
0.507	0.316	0.923	0.0118	0.037	1.0	0.005	0.130	0.17

2.2. Fabrication of Leaf Spring

In the first stage of production, cutting of plates was carried out. The plates were cut with special cutting saws to be 1290 mm long and 100 mm thick. The leaf spring plates are shown in Fig. 1.

Fig. 1. Cutting of plates for leaf spring manufacturing

The center hole is drilled on the specially designed CNC turning machine with a cut leaf spring. The center hole guides the leaf spring center bolt. This situation is given in Fig. 2. Drilling is performed by applying force with the drill bit and rotating to the desired point of the leaf spring-loaded on the machine. Cooling fluids are used to prevent the high heat generated during the drilling process.

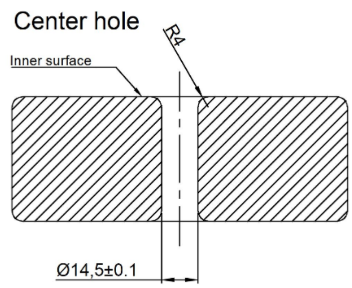

Fig. 2. Center hole

In this study, the plates used for leaf spring production were heated 350°C. The heated plates were rolled by passing them through the rollers. The heating of the leaf spring plates is shown in Fig. 3.

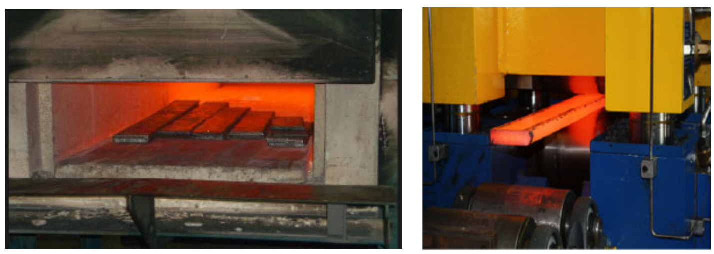

Fig. 3. Heating of leaf spring plates

Afterward, the leaf spring is given an eye forming to one side and the end cutting form (Z type form) is created in the part where no eye is present. This form is shown in Fig. 4.

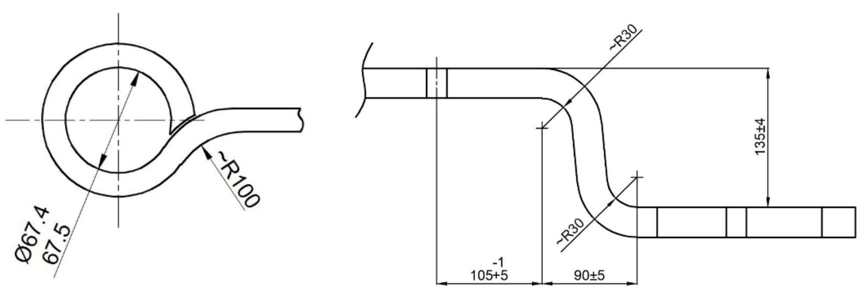

Fig. 4. Eye and final form

Leaf springs are annealed at 850ºC -1500ºC depending on the spring thickness and shape of the cut. The Z type leaf spring in this study was annealed at 965ºC in a furnace. Oil is given between 850ºC -870ºC and 30 minutes for the quenching process and to prevent the formation of decarburization on the spring. In addition, leaf spring was tempered at 400ºC and 2 hours. These processes are shown in Fig. 5. With this process, the material structure has been turned into tempered martensite.

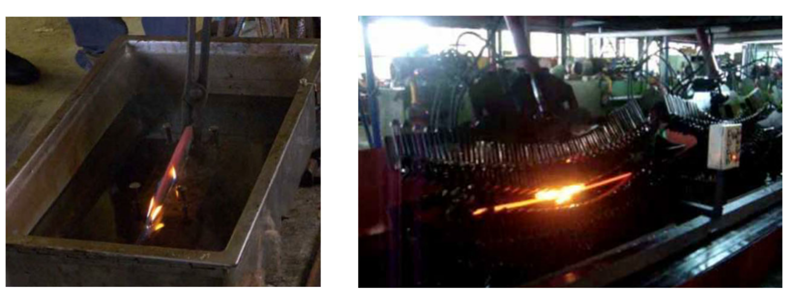

Fig. 5. Quenching and tempering process for Z type leaf spring

Shot peening was applied to the springs to adjust the spring stiffness, surface roughness and residual stress. Balls are thrown onto the spring at certain speeds. The size of the balls used for leaf springs is min 0,18 Almen. Afterward, leaf springs were covered with black cataphoresis to delay corrosion. The cataphoretic film thickness should be between 15-55 microns. Bolts, spacers, clamps and leaf layers of all samples whose heat treatments are completed were assembled. Fig. 6 shows the Z type leaf spring assembly.

Fig. 6. Z type leaf spring assembly stage

Finally, the curvature that cannot be obtained during production was provided by the pre-loading of the molds. Pre-loading conditions are shown in Fig. 7.

Fig. 7. Pre-loading of Z type leaf spring

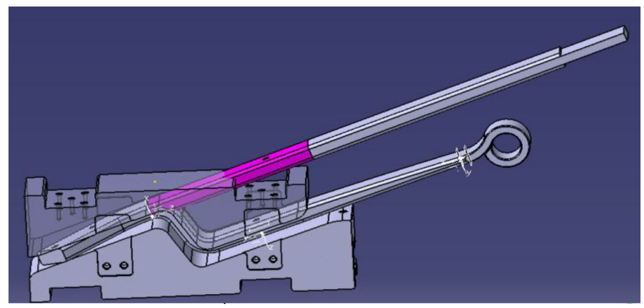

Fig. 8. The prepared mold of the Z type leaf spring

The mold of leaf spring was prepared by using Tata Ace leaf spring. Aluminum is used as a mold material. The prepared mold of the Z type leaf spring is shown in Fig. 8.

3. Results and Discussion

3.1 Residual Stress Measurement

The residual stress values of the samples in this study were determined by the X-ray diffraction method. Residual stresses on the leaf spring were determined according to the peaks taken from the X-Ray device. Measurements were obtained by portable Stresstech XStress 3000 G2R XRD device. This device is shown in Fig. 9.

Fig. 9. XRD stress analyzer device

Table 2. Residual stress values

Residual stress for tensile surface	Residual stress for compressive surface
-625 MPa	+284 MPa

According to the DBL 9020 reference, the user of the product has specified a minimum residual stress value of 600 MPa for the tensile surface and a minimum of 200 MPa for the compression surface. Table 2 shows that reference values are provided.

3.2 Hardness Test

Hardness test is based on optical measurement of the trace made by the diamond cone tip on the material, through loads selected depending on the material type and thickness. In the study, the hardness value was determined as 486 HB by applying the diamond cone tip to the leaf spring material with a pre-load load of 9.8 N for 15 seconds. The measurements in the study were carried out on a BMS brand / 3000-OBPC model Brinell hardness measuring device. This device is shown in Fig. 10.

Fig. 10. Brinell hardness test device

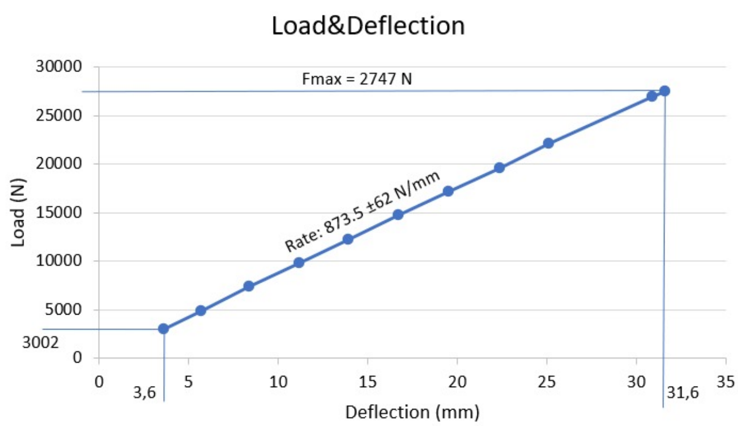

Fig. 11. Z type leaf spring load-deflection diagram

3.3 Bending Test

The leaf spring is placed in the prepared test fixture. Loads are applied to the spring gradually and the deflection values are recorded. These values are given in Table 3.

Table 3. Load and deflection values in Z type leaf spring

Load (N)	Deflection (mm)
3002	3.6
4905	5.7
7350	8.4
9810	11.2
12263	13.9
14715	16.7
17160	19.5
19620	22.4
22073	25.1
26978	30.9
27497	31.6

The spring has a load from zero to the determined maximum deflection. According to the obtained values, the spring load-deflection graph was drawn as in Fig. 11.

3.4 Strain Gauge Measurement

Strain gauges were placed in various regions of the leaf spring and force-tension data were collected. This situation is illustrated in Fig. 12.

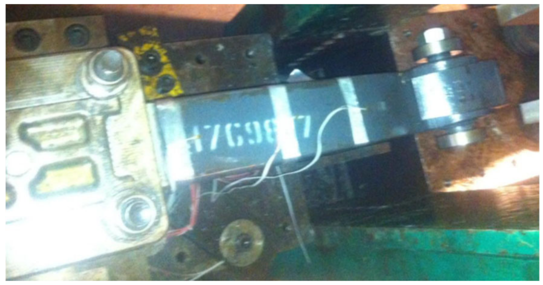

Fig. 12. Strain gauge on leaf spring

Stress values obtained with the strain gauge were measured at 250 mm, 500 mm and 750 mm distances from the center hole. The stress values obtained according to the distance are given in Table 4.

Table 4. Strain gauge measurements

Loads (N)	Stress at 250 mm distance [MPa]	Stress at 500 mm distance [MPa]	Stress at 750 mm distance [MPa]
0	0	0	0
2500	64.3	68.7	68.8
5000	99.7	105.9	106.8
10000	182.7	196.7	206.4
15000	271.4	289.3	317.5
20000	364.8	379.1	402.2
27500	497.2	518.3	575.6

The strain gauge stress values reported by the company are 475 MPa for 250 mm distance, 500 MPa for 500 mm distance and 540 MPa for 750 mm distance. The values obtained, as shown in Table 4, provide reference data.

3.5 Microstructure Analysis

The hot rolled sample was examined under Nikon brand optical microscope. Fig. 13 shows the microstructure of the sample.

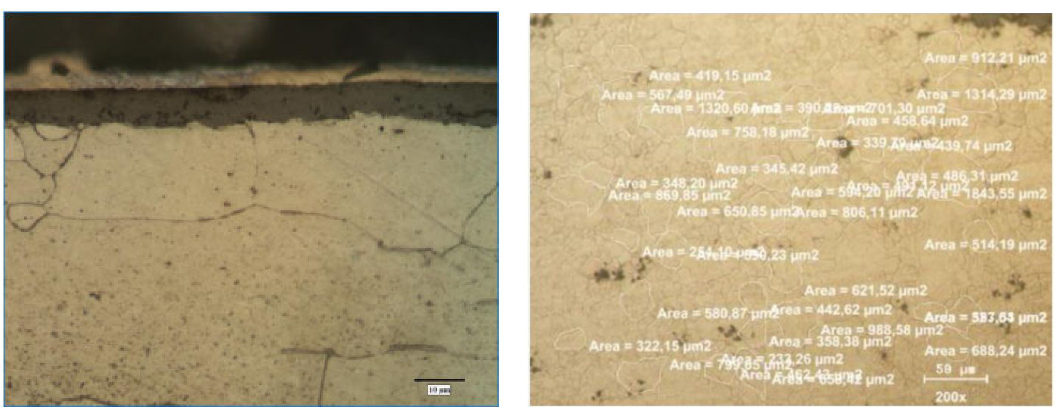

Fig. 13. Microstructure analysis

Surface characterization and grain size measurements for the Z-type leaf are given in Table 5. As seen in the section view, the tufting thickness on the surface was determined as 46.51 µm. The grain size was calculated according to the number of grains per a certain area with the ASTM standard. In addition, it is observed that cracks and oxidation do not occur on the microstructure surface.

Table 5. Surface characterization and grain size

	Reference	**Data**
Crack depth	It should be %1 the material thickness and can be max. 0,3 mm for all.	Not be seen.
Sinking depth of tufting at surface	Should be max 70 µm	46,51 µm
Grain size	≥5	7-8
Surface oxidation	Shouldn't be.	Not be seen.

4. Conclusion

In this study, prototype production of Z type leaf springs used in air suspension systems was carried out. This production started with the initial stage of cutting the plates and continued with heat treatments, bending and forming processes. The spring plate materials, the heat treatment parameters of the spring and the details of the eye form were given to create the spring prototype.

To determine the mechanical properties of the spring, first of all, residual stress was measured with the help of X-rays. According to the obtained data, it is concluded that the spring can carry the residual stresses on it. To determine the mechanical properties of the spring, firstly the residual stress was measured with the help of X-rays and then the hardness test was applied. According to the obtained data, it has been concluded that the spring can carry residual stresses and provides the standard in terms of hardness. The deformation values that occur as a result of the loading on the spring were determined. Accordingly, the characteristic load-deflection curve of the spring was created. It has been observed that the spring proceeds with a linear slope in terms of spring stiffness. It was determined that the strain gauge values were also within the given limit values. When the surface characterization of the spring is examined, no cracks, scale layer and oxidation were observed on the material surface. It is seen that the grain sizes also provide the standard value.

As a result, in the study, Z type leaf spring used in suspension systems, prototype production stages, the physical and heat treatment parameters applied to the sample are included. It has also been confirmed by the mechanical and microstructural tests that the prototype sample was produced by the standards.

5. Acknowledgement

The author would like to thank the “Ministry of Industry and Trade” and the company “Olgun Celik” for their support in this study and the implementation of the project as the “San-Tez project no: 0388.STZ.2013-2”.

References

Al-Qureshi, H. A. (2001). Automobile leaf springs from compound material. *Material Processing Technology*, *118*, 58-61.

Atig, A., Sghaier, R. B., Seddik, R., & Fathallah R. (2018). Probabilistic methodology for predicting the dispersionof residual stresses and Almen intensity considering shot peening process uncertainties. *International Journal Advanced Manufacturing Technologies*, *94*, 2125–2136.

Tokgönül, G., Kulaç, G., Şenocak, Ç., & Başalan, E. (2018). Single layer parabolic leaf spring production and physical verification for heavy commercial vehicles. *Journal of Soma MYO Technical Sciences*, *26*, 55-61.

Başaran, A., Varol, R., Pirge, G., Baştürk, S., & Varol, H. (2007). *Investigation of the shot peening effect of elevated temperature on the fatigue strength of cubber added P/M steels* [Conference presentation], 8th International Fracture Conference, Istanbul, Turkey.

Singh, H., & Singh Brar, G. (2018). Characterization and investigation of mechanical properties of composite materials used for leaf spring. *Materials Today: Proceedings*, *5*, 5857-5863.

Ganesh, R., Chavhan, L., & Wankhade, N. (2020) Experimental analysis of E-glass fiber/epoxy composite-material leaf spring used in automotive. *Materials Today: Proceedings*, *26*, 373-377.

Akgümüş Gök, D., & Baltacı, A. (2023). Design and fatigue life analysis of air suspension Z type leaf springs used in heavy commercial vehicle. *Journal of Polytechnic*, *26*(1), 249-255.

Scuracchio, B. G., Batista de Lima, N., & Schön, C. G. (2013). Role of residual stresses induced by double peening on fatigue durability of automotive leaf springs. *Materials and Design*, *47*, 672–676.

Gandhi, S., Chinnasamy, V., & Kumaravelan, R. (2014). Performance analysis of leaf spring by contact mechanics approach based on the nature of material properties. *Transactions of Famena*, *38*, 87–96.

Hao, K. M., Xu, W. B., & Li, B. (2013). Design of test bench for automotive leaf spring. *Advanced Materials Research*, *834-836*, 1718–1722.

Savaidis, G., Savaidis, A., & Malikoutsakis, M. (2013). *Leaf spring suspension design of commercial vehicles based on theoretical methods* [Conference presentation], 3th International Power Transmissions Conference, Halkidiki, Greece.