POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)
URL: http://dergipark.org.tr/politeknik

Design and fatigue life analysis of air suspension z type leaf springs used in heavy commercial vehicle

Ağır ticari araçlarda kullanılan hava süspansiyonlu z tipi yaprak yayların tasarımı ve yorulma ömrü analizi

***Yazar(lar) (Author(s))**: Dilşad AKGÜMÜŞ GÖK[1], Aysun BALTACI[2]*

ORCID[1]: 0000-0003-3403-3815

ORCID[2]: 0000-0002-9049-1610

To cite to this article: Akgümüş Gök D. and Baltacı, "Design and fatigue life analysis of air suspension z type leaf springs used in heavy commercial vehicle", ***Journal of Polytechnic***, 26(1): 249-255, (2023).

Bu makaleye şu şekilde atıfta bulunabilirsiniz: Akgümüş Gök D. and Baltacı, "Design and fatigue life analysis of air suspension z type leaf springs used in heavy commercial vehicle", ***Politeknik Dergisi***, 26(1): 249-255, (2023).

Erişim linki (To link to this article): http://dergipark.org.tr/politeknik/archive

DOI: 10.2339/politeknik.822648

Design and Fatigue Life Analysis of Air Suspension Z Type Leaf Springs Used in Heavy Commercial Vehicle

Highlights

- *Z type leaf springs are generally used in air suspension systems for heavy commercial vehicles.*
- *Leaf springs are also used to locate the axle and control the height at which the vehicle rides.*
- *Z type leaf springs are used to carry less load in axles and chassis, provide to ride comfort and good vehicle handling comfort to the driver.*
- *Before the prototype production, leaf springs are designed for different road conditions, stress and fatigue life analyzes are performed.*

Graphical Abstract

In this experimental study, design and finite element model of Z leaf spring were prepared. And then, form and stress analyzes were performed on the model.The fatigue life of this spring was obtained in the N-Code program.

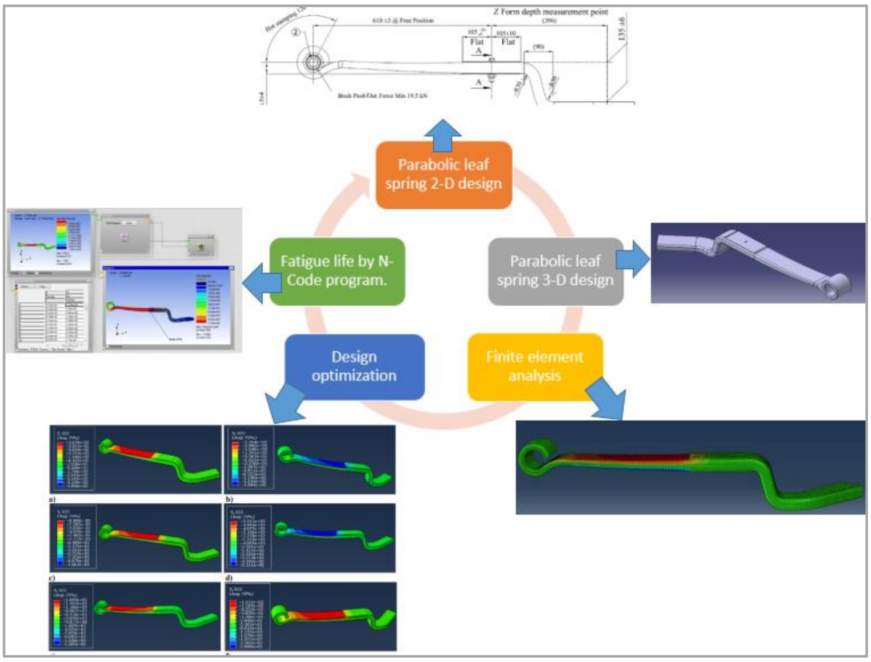


Figure. Graphical Abstract

Aim

The Z type leaf spring designed within the scope of this study is aimed to provide more durable, more deflection and longer fatigue life than other similar air bellows springs.

Design & Methodology

In this study, Z type parabolic leaf spring design and 3D modeling were made under different loading conditions.

Originality

The leaf produced within the scope of the study was tested for the first time in the air suspension systems of heavy commercial vehicles.

Findings

According to the all loading situation, stress values of Z type leaf spring did not exceed 1000 MPa and result of fatigue analyzes obtained a minimum of 100000 cycles was achieved.

Conclusion

With the analyzes obtained it is made possible to realize prototype production of Z type parabolic leaf spring used in air suspension systems.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Ağır Ticari Araçlarda Kullanılan Hava Süspansiyonlu Z Tipi Yaprak Yayların Tasarımı ve Yorulma Ömrü Analizi

Araştırma Makalesi / Research Article

Dilşad AKGÜMÜŞ GÖK[1*], Aysun BALTACI[2]

[1]Istanbul Aydin University, Faculty of Engineering, Department of Mechanical Engineering, Istanbul/Turkey

[2]Ege University, Faculty of Engineering, Department of Mechanical Engineering, Izmir/Turkey

(Geliş/Received : 06.11.2020 ; Kabul/Accepted : 09.11.2021 ; Erken Görünüm/Early View : 26.11.2021)

ÖZ

Otomotiv sektöründe özellikle ağır ticari araçlarda araçların ön ve arka akslarında süspansiyon elemanı olarak yaprak yaylar kullanılmaktadır. Her türlü yol koşulunda ve yük altında çalışan yaprak yaylar, tekerlekten ve yerden şasiye iletilen yüklerin sönümlenmesini sağlar. Bu sayede araçta güvenlik ve çalışma konforu sağlar. Yeni nesil araçlarda mekanik süspansiyon sistemleri yerini havalı süspansiyon sistemlerine bırakmıştır. Havalı süspansiyon sistemlerinde; Özellikle ağır ticari araçlarda kullanılan Z tipi parabolik yaprak yaylar, hava körükleri ile geri esneme sağlayan yaprak yay türüdür. Bu çalışmada, Z tipi parabolik yaprak yay tasarımı ve bu yayın sonlu elemanlar analiz yöntemi ile hazırlanan model üzerinden form ve gerilme analizleri yapılmıştır. Sonlu elemanlar analizi kullanılarak bu yaprak yayın yüksek gerilim bölgeleri belirlenmiş ve uygun tasarım seçilmiştir. Son olarak N-Code programında ve fiziksel testler ile bu yaprak yaya ait yorulma ömrü elde edilmiştir.

Anahtar Kelimeler: Z tipi yaprak yay, parabolik yaprak yay, süspansiyon sistemleri, sonlu elemanlar.

Design and Fatigue Life Analysis of Air Suspension Z Type Leaf Springs Used in Heavy Commercial Vehicle

ABSTRACT

Leaf springs are used as suspension elements in the front and rear axles of vehicles in the automotive industry, especially in heavy commercial vehicles. Leaf springs working all road conditions and under load, it provides damping of the loads transmitted from the wheel and from the ground to the chassis. In this way, it ensures the safety and working comfort in the vehicle. Mechanical suspension systems have been replaced by air suspension systems in new generation vehicles. In air suspension systems; Z type parabolic leaf springs, especially used in heavy commercial vehicles, is a type of leaf spring that provides spring back with air bellows. In this study; Z type parabolic leaf spring design and finite element model of this leaf spring were prepared and form and stress analyzes were performed on the model. By using finite element analysis, high-tension regions of this leaf spring were determined and the appropriate design was selected. Finally, the fatigue life of this spring was obtained in the N-Code program and physical test.

Keywords: Z type leaf springs, parabolic leaf springs, suspension systems, finite elements.

1. INTRODUCTION

Leaf spring is one of the oldest components used in the suspension system of heavy commercial vehicles due to its high load capacity and cost. Leaf springs have a longer life since they share the amount of load they carry. Leaf springs have wide usage in vehicles, mostly on the load carrying such as trucks, vans, or pick-up trucks [1]. Conventional and parabolic leaf springs have mechanical suspension systems. Mechanical suspension systems have been replaced by air suspension systems in new generation vehicles. Air suspension systems are mostly used in trucks, buses, and luxury passenger cars [2]. The spring back effect is ensured by mechanically or electronically controlled air discharge to the bellows and discharge of air. So that ensured that the height of the vehicle during driving is kept constant under all conditions. Air suspension springs have been cylindrical or accordion bellows [3]. The bellows of the cylindrical type move up and down according to the movements of the suspension system. Accordion bellows work by expanding or squeezing due to their ducted structures formed by reinforcing segments. Air suspension springs in vehicles are used to instead or support the steel springs of the rear axles [4].

Z type leaf spring geometry compares a half parabolic leaf spring and air suspension spring. Unlike conventional springs, air suspension springs fix the distance of the vehicle's chassis position to the ground by showing geometric changes due to the change of air in the bellows during operation and due to its flexible material structure. These springs have a longer life since they share the amount of load they carry [5].

**Corresponding Author*

e-posta : dilsadakgumus@aydin.edu.tr

There are different approaches that have been used in literature. Kanbolat et al. [6] applied the design of experiment method to correlate experimental and simulation results where unnecessary limits on tolerances and design changes were eliminated. This study was conducted on a vertical test bench which can be actuated only in the vertical direction. Enders [7] worked on the correlation of shaker rig tests and simulations. After applying the friction model to the system, the results were significantly improved. Pradeep et al. [8] designed a single leaf glass fibre reinforced plastic spring with thickness as the variable and with the same geometrical and mechanical properties to multi leaf steel spring. Karthik Badugu et al. [9] described the manufacturing of fibre glass, its development, and static load test analysis of composite leaf spring made from glass fibre reinforced polymer. Deshmukh et al. [10] leaf spring is widely utilized as an automotive suspension in the industry and they prevent the harmful effects of the good shocks on vehicle components, secure the vehicle stability, and provide ride comfort.

Computer aided design and analysis methods take an important place in the automotive industry. The developing technology aims to simulate accurate models instead of testing design by engineers. In this study; the design of Z type leaf springs, which are used in air bellows suspension systems of heavy commercial vehicles, has been made considering the structural features and design limitations of these springs. 3D solid modelling of air bellows Z type parabolic leaf springs, designed by Catia, and finite element stress analysis were performed by the Abaqus program. The most suitable design was determined by the stress analysis. Fatigue life of this leaf spring was obtained in the N-Code program.

2. MATERIAL and METHOD

Z type parabolic springs are special type springs produced for use in air bellows suspension systems. In this study, it is aimed to design and verify the design of Z type leaf springs according to the boundary conditions in the vehicle. 52CrMoV4 spring steel material was selected for this spring in accordance with EN 10089 standard. First of all, design criteria were determined for a leaf spring that provides the comfort conditions of the vehicle, conforms to the load-deflection diagram, and have low stresses.

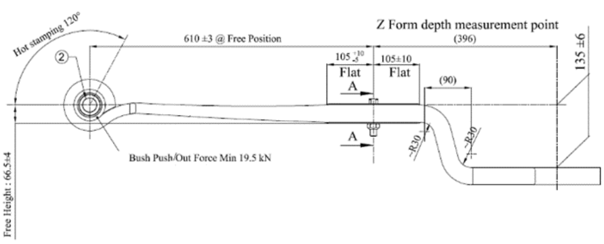


Figure 1. Z type parabolic leaf spring design

First of all, design criteria were determined for a leaf spring that provides the comfort conditions of the vehicle, conforms to the load-deflection diagram, and have low stresses. 3D solid model was created in the Catia program of the designed leaf spring. In the next stage, this leaf spring was prepared for form and stress analysis by meshing. In Figure 1, the Z type parabolic leaf spring designed within the scope of the study is given.

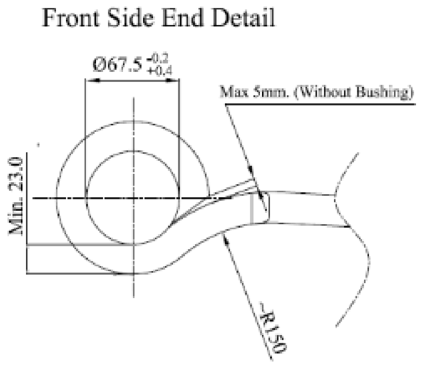


Figure 2. Z type parabolic leaf spring eye section design

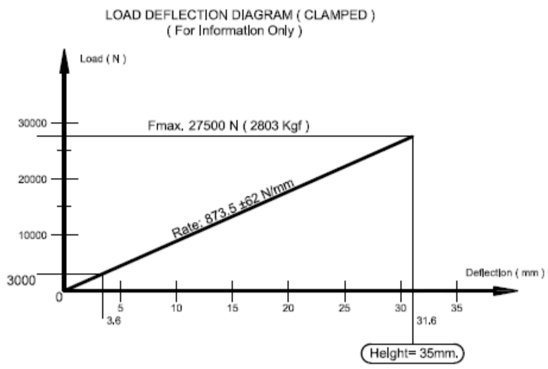


Figure 3. Z type parabolic leaf spring load-deflection diagram

The load-deflection graph in Figure 2 and Figure 3 were obtained depending on the loads determined by the customer and the deflection values calculated depending on the distance from the center where the loads given in Table 2 are applied.

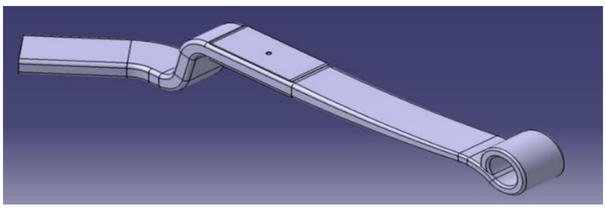


Figure 4. Perspective view of designed leaf spring

Since the leaf spring core region does not work while driving, the hole in this region has no to effect on the analysis. Meshing this area is not easy. Therefore, the bolts and holes on the leaf spring were removed while preparing the data for analysis. The 3D view of the Z-type parabolic leaf spring designed in Figure 4 is given.

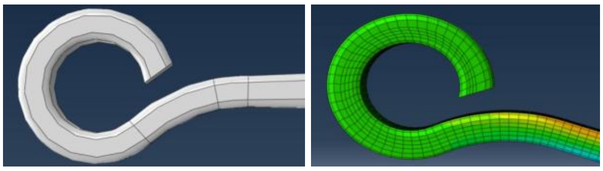


Figure 5. Cutting the eye part of the leaf spring

The tip of the eye was cut to some extent as it touched the leaf spring body under a certain load, causing an imbalance in the results. The 3-dimensional view of the Z-type parabolic leaf spring designed is given in Figure 5.

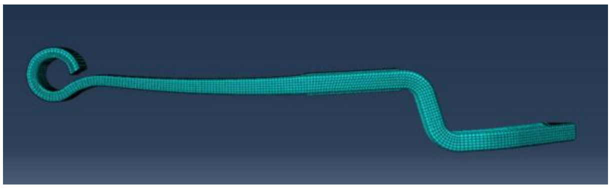
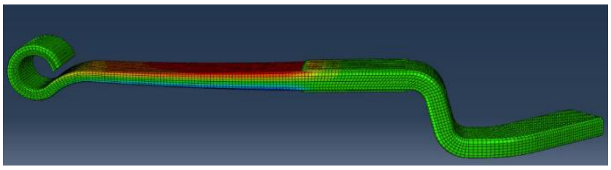


Figure 6. The meshing of leaf spring

For the Z type leaf spring design, the number of mesh is taken as 21900 and the number of joints as 28661. In Figure 6, the meshed form of the designed leaf spring is shown. The part of the mesh, which is set for the analysis of the leaf spring, is also given in Figure 7.



. **Figure 7.** The meshing of leaf spring

Finite element analysis was performed for different loading conditions acting on the vehicle and the stress values on the leaf spring were found. Force and moment loads were applied from the eye of Z type leaf spring. The

3. RESULTS and DISCUSSION

Boundary conditions of finite elements were simplified suitably and implemented to the model. The hole plate in the core region of the Z type parabolic leaf spring is considered to be a fixed support and the loading is made from the eye. This situation is shown in Figure 8.

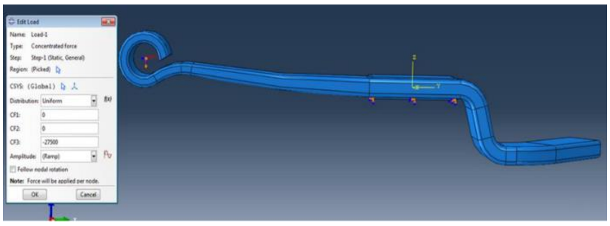


Figure 8. Boundary and loading conditions

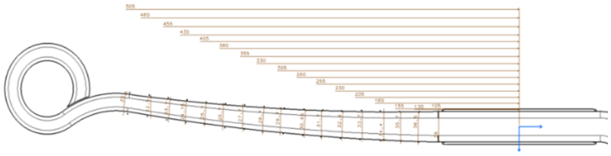


Figure 9. Thickness values determined for the design

The thickness values tried for the design on the leaf spring are given in Figure 9. Stress values for leaf spring design were calculated according to the thickness values and parabolic spring's formulas. The formulas are given in Figure 10.

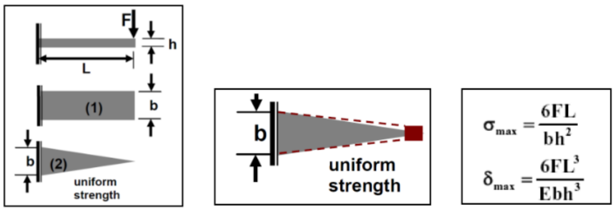


Figure 10. Parabolic spring's formulas

Table 1. Loading conditions

	Fx (N)	Fy (N)	Fz (N)	Mx (N.mm)	My (N.mm)	Mz (N.mm)
Loading 1	63875,64	-1687,65	18175,36	-4726,23	-	2284,31
Loading 2	8193,29	-25577,80	-11642,00	6842,59	-	-6066,14
Loading 3	12655,79	7708,00	45002,36	136832,90	-5572,88	-59734,50
Loading 4	-18219,80	-10519,70	-23165,20	235351,40	1924,51	-
Loading 5	23204,39	-5728,29	3746,40	1419,79	-	-604,37
Loading 6	-27614,40	-11028,40	9060,79	-58982,60	580,60	-

loading conditions are given in Table 1. Six loading conditions given by the customer are the loads that the vehicle can be exposed to in bad road conditions.

The values calculated for the design, taking into account the loading conditions determined by the customer and using the leaf spring design formulas above, are given in Table 2.

Table 2. Loading conditions

Distance from the center (mm)	Width (mm)	Thickness (mm)	Stress (MPa)	Deflection (mm)	Rate (N/mm)
0	100	38	697.0	32.9	834.0
105	100	38	577.0	18.7	1469.9
130	100	36.5	594.5	18.17	1516.9
155	100	35.7	589.1	16.5	1666.3
180	100	34.4	599.6	15.6	1766.4
205	100	33.7	588.4	13.8	1987.7
230	100	32.9	579.3	12.3	2239.0
255	100	31.7	582.9	11.2	2456.5
280	100	30.6	579.6	9.9	2764.2
305	100	29.7	570.5	8.6	3185.6
330	100	28.7	560.9	7.4	3715.3
355	100	27.7	548.4	6.2	4422.2
380	100	26.7	532.3	5.1	5397.2
405	100	25.7	512.1	4.0	6797.6
430	100	24.75	484.8	3.1	8968.6
455	100	23.7	455.3	2.2	12333.0
480	100	22.5	423.7	1.5	17886.9
505	100	22	357.9	0.9	31733.6
610	100	22	0	0	0

The spring stiffness coefficient of the design was calculated by finite element analysis. This coefficient was calculated according to the vertical load F_{max} = 27500 N. According to the analysis results, leaf spring design optimization was performed. For optimum design, a stress value of not more than 1000 MPa and desired spring stiffness value must be provided. Stress analysis was applied to Z type leaf springs for six different road conditions determined by the customer. These values are given in Table 3.

Table 3. Stress values under different loading conditions

Loading Conditions	Stress (MPa)
Loading 1	462.8
Loading 2	-189.9
Loading 3	890.8
Loading 4	-511.1
Loading 5	169.9
Loading 6	151.2

The first loading state is the loading condition where F_x and My are the highest. For this reason, the stress value in the eye region was considered. The second loading state is the loading condition where F_y and M_y are the highest. This loading occurs when the leaf spring compressive force and the leaf spring is pulled upwards. This road condition is caused by vehicles jumping in bumps or pits. The third loading state is the loading condition where F_z and M_x are the highest. Loading in the Z direction is the worst road condition. However, the obtained stress value is within the acceptable limit. The highest stress value was obtained in all loading conditions. The fourth loading state is the loading condition where F_z and M_x are the highest. It has similar road conditions with the second loading condition. The fifth loading state is the loading condition where F_x and M_y are the highest. This loading condition occurs when the vehicle is braking. The stress values are very low due to the braking condition. The sixth loading state is the loading condition where Fx and Mz are the highest. This road condition occurs when the vehicle is driving. These six loading conditions are given in Figure 11.

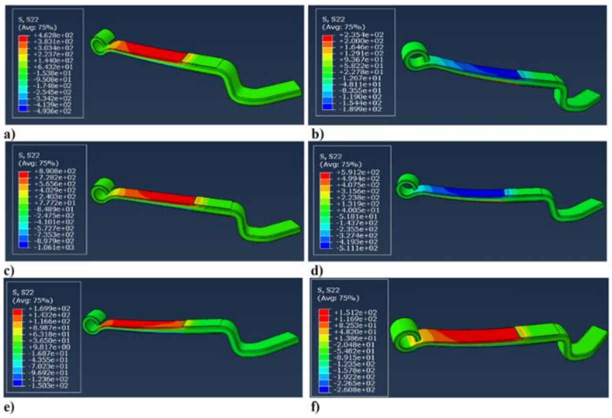


Figure 11. Stress analyses for the six loading conditions; a) First loading condition, b) Second loading condition, c) Third loading condition, d) Fourth loading condition, e) Fifth loading condition, f) Sixth loading condition

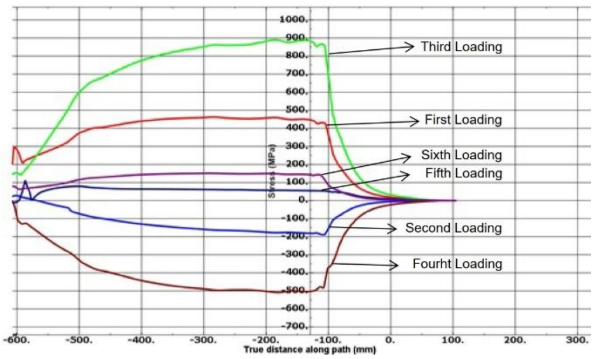


Figure 12. Stress detection along the road for all loading conditions

The stress values obtained did not exceed 1000 MPa when all road conditions were examined. Therefore all loading conditions are within acceptable limits. All stress variations are shown in Figure 12.

Leaf spring is a critical suspension element that is subjected to various dynamic loads under different road conditions. For this reason, the determination fatigue life of leaf springs is important. Stresses in vertical loading (F_{max} = 27500) from Abaqus were transferred to the N-Code program. As a result of these inputs, the most critical fracture zone was determined with the N-Code program. Figure 13 shows the calculation of the designed leaf spring life in the N-code program.

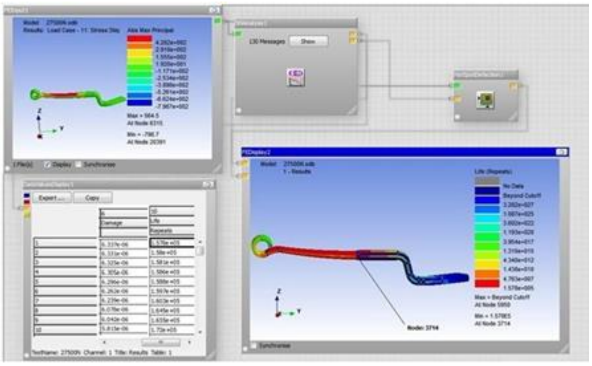


Figure 13. Determination of Z type leaf spring life

The highest damage is where the fracture will occur. This is explained by the lowest number of cycles. Fatigue life (number of cycles) is equal to "1 / damage". As a result of the data entered in the N-Code, the critical expected number of cycles was calculated as 157800. In this study, the desired number of cycles is 100000 and the values obtained are suitable.

In addition to the analyzes made on the N-code program, life tests were carried out with a test fixture that simulates the position of the leaf spring received by the customer

Table 4. Fatigue analysis results

Loadings	Requested Fatigue Cycle	Test Load (Min.)	Test Load (Max.)	Fatigue Test Results
Loading 1	100000	3 kN	27.5 kN	166013 cycle leaf is broken 235 mm from the center hole
Loading 2	100000	3 kN	27.5 kN	156935 cycle leaf is broken 472 mm from the center hole
Loading 3	100000	3 kN	27.5 kN	158432 cycle leaf is broken 505 mm from the center hole
Loading 4	100000	3 kN	27.5 kN	171385 cycle leaf is broken 120 mm from the center hole
Loading 5	100000	3 kN	27.5 kN	143503 cycle leaf is broken 105 mm from the center hole
Loading 6	100000	3 kN	27.5 kN	152604 cycle leaf is broken 85 mm from the center hole

in the vehicle. The test fixture created is given in Figure 14.

Figure 14. Fatigue analysis test fixture

A fatigue test was performed on the Z type leaf spring prototype within the scope of the study, and it provided the desired minimum cycle value of 100000 cycles. The fatigue analysis results are shown in Table 4.

While the average cycle value of the physical tests is 158145 cycles, the value calculated in the N-Code program is 157800 cycles. Since the values are very close to each other, the physical test results were confirmed with each other by the life analysis made in the N-code program.

5. CONCLUSION

In this study, Z type parabolic leaf spring design and 3D modelling were performed. Stress analyzes were obtained by finite element analysis under different loading conditions of this leaf spring. The fatigue life of this leaf spring was determined. According to the all loading situation, it was ensured that the stress values of Z type leaf spring, which were designed and analyzed, did not exceed 1000 MPa, and spring hardness coefficient was obtained in the predicted range. As a result of fatigue analyzes obtained both in the N-code program and physical tests, a minimum of 100000 cycles was achieved. Thus, the leaf spring is designed to be assembled on the axle without adversely affecting the axle and chassis connection of the vehicle. The Z type leaf spring designed in this study is more durable, has more deflection, and provides longer fatigue life cycles than other similar air bellows springs. If the analysis results are taken into consideration, it is made possible to realize prototype production of Z type parabolic leaf spring used in air suspension systems.

ACKNOWLEDGEMENT

The authors 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".

DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Dilşad AKGÜMÜŞ GÖK: Performed the experiments and analyse the results. Writing the manuscript.

Aysun BALTACI: Analysed the results. Reviewing the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Al-Qureshi H.A., "Automobile leaf springs from composite materials", ***Journal of Materials Processing Technology***, 118: 58–61, (2001).

[2] Decker M. and Savaidis G., "Measurement and analysis of wheel loads for design and fatigue evaluation of vehicle chassis components", ***Fatigue & Fracture of Engineering Materials & Structures***, 25: 1103–1119, (2002).

[3] Gandhi S., Chinnasamy V. and Kumaravelan R., et all., "Performance analysis of leaf spring by contact mechanics approach based on the nature of material properties", ***Transactions of Famena***, 38: 87–96, (2014).

[4] Hao K.M., Xu W.B. and Li B., "Design of test bench for automotive leaf spring", ***Advanced Materials Research***, 1718–1722, (2013).

[5] Kanbolat A., Soner M. and Karaağaç M., "Parabolic leaf spring optimization and fatigue strength evaluation on the base of road load data, endurance rig tests and non-linear finite element analysis", ***SAE Technical Paper Series***, (2011).

[6] Jonson O. and Enders E., "Correlation work on shaker rig tests and simulations", ***Master's Thesis***, Chalmers University of Technology, Department of Automotive Engineering, (2016).

[7] Pradeep R., "Experimental evaluation and finite element analysis of composite leaf spring for automotive vehicle", ***Middle-East Journal of Scientific Research***, 17: 1760-1763, (2013).

[8] Srivastava A. and Choudhary S., "Design and structural analysis of Jute/E-glass woven fiber reinforced epoxy based hybrid composite leaf spring under static loading", ***International Journal of Mechanical Engineering and Research***, 3: 573-582, (2013).

[9] Deshmukh B.B. and Jaju S.B., "Design and analysis of glass fiber reinforced polymer (GFRP) leaf spring", ***In 2011 Fourth International Conference on Emerging Trends in Engineering & Technology***, IEEE, 82–87, (2011).

[10] Huizinga F.T.M.J.M., Van Ostaijen R.A.A. and Van Oosten Slingeland A., "A practical approach to virtual testing in automotive engineering", ***Journal of Engineering Design***, 13: 33–47, (2002).

[11] Kong Y.S., Omar M.Z., Chua L.B. and Abdullah S., "Fatigue life prediction of parabolic leaf spring under various road conditions", ***Engineering Failure Analysis***, 46: 92–103, (2014).

[12] Malikoutsakis M., and Savaidis G., "Calculation of mechanical response of leaf springs using nastran and

abaqus–a comparative study", ***31st International Symposium on Mechanics of Materials***, 151-158, (2010).

[13] Omar M. A., Shabana A. A. and Mikkola A., "Multibody system modeling of leaf springs, Journal of Vibration and Control", ***Journal of Vibration and Control***, 10(11): 1601-1638, (2004).

[14] Wu N., "Finite element analysis of automobile leaf spring bassed on Pro/E", ***Advanced Materials Research***, 1250–1253, (2013)