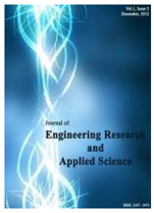
Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 12 (1), June 2023, pp 2285-2290
ISSN 2147-3471 © 2023



Topology Optimization of Leaf Spring Brackets in Truck Suspensions

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Accepted 15 May 2023

Abstract

Through the use of structural optimization methods, it can help to design brackets as light, strong and safe. Leaf spring brackets are an important part used for attaching and fixing leaf springs in vehicle suspension systems. The design of the leaf spring brackets has a significant impact on the suspension system performance, handling, driving comfort, and safety of the vehicles. In this study, first of all, the materials used in the leaf spring brackets were investigated. After the material analysis, the most suitable material for the alternative leaf spring brackets developed for the suspension system of a commercial vehicle was determined. Modeling of various designs of these leaf spring brackets was done in Catia V6, a package program. After the modeling process was done in the package program, static analyses were made with the Ansys Finite Element Analysis program. As a result of the examination of the leaf spring brackets, the alternative spring bracket design of the truck, which is a heavy tonnage commercial vehicle, was developed and the topology optimization of the bracket was carried out according to the results of the analysis with the ANSYS Finite Elements program. Thus, the selection of the appropriate leaf spring bracket for this selected vehicle has been carried out.

Keywords: *Leaf spring brackets, Topology optimization, Static analysis, Truck Suspension*

1. Introduction

Along with the developing and changing technology, comfort, and safety systems are also being developed while efficiency is increasing. Increasing customer expectations and developing technologies have revealed the necessity for commercial vehicles to be at least as comfortable as automobiles. Leaf spring brackets are an important part used for attaching and fixing leaf springs in vehicle suspension systems. It is only possible with an approach to an advanced suspension system that the vehicles have safe and better driving, braking, acceleration, high speed, and cornering demands in various load and driving environments and the tires hold onto the road. The design of the leaf spring brackets has a significant impact on the suspension system performance, handling, driving comfort and safety of the vehicles. There are challenges associated with the characteristics of heavy-duty vehicles, traveling on high-speed roads, and a high center of gravity [1]. Leaf springs are found to be durable and inexpensive in that they are good at isolating road-incited vibrations and supporting vertically acting loads. Therefore, the static and dynamic examination of the leaf spring is extremely important for predicting quality and vibration characteristics [2].

Some researchers published about the optimization of suspension systems in commercial trucks in the literature [3-10]. Sert and Boyraz [11] presented the commercial vehicle rollover threshold can be improved through tuned soft suspension and increased stiffness of the anti-roll bar and leaf spring by using three different anti-roll bars and two different front leaf springs during the tests to perform parametric sensitivity analysis and examine the effect of components on stability performance. Bhandarkar and Shekhawat [12] developed the methodology to design the leaf spring rear suspension for the rear engine by using Finite element analysis. Their results showed that the challenges in designing leaf spring rear suspension for the rear engine are different from those for the front engine. Some authors [13-17] have successfully presented the topology optimization of light or heavy commercial trucks using various pocket programs such as ANSYS, CATIA, and FEA.

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In this study, The design and examination of the leaf spring connection brackets in the suspensions of heavy-duty trucks are explained, and topology optimization is made. The most suitable material for the alternative leaf spring brackets developed for the suspension system of a commercial vehicle was determined, Modeling of various designs of these leaf spring brackets was done in Catia V6, a package program. The topology optimization of the bracket was carried out according to the results of the analysis with the ANSYS Finite Elements program. Static analyzes were carried out in different scenarios in order to evaluate the resistance of the leaf spring connection bracket, which is planned to be produced by welded or casting production method, against the loads coming with the determined boundary conditions. The selection of the appropriate leaf spring bracket for this selected vehicle has been carried out.

2. Topology Optimization of Leaf Spring Brackets

The design of products with high performance and reduced weight has increased with the developing technology and has gained great importance for production processes. For this purpose, in the design processes, the product is provided with the appropriate structure by making structural optimization. Among the structural optimization methods, which are divided into three sizes, shape, and topology optimization, topology optimization is considered to be the most comprehensive method as it provides engineers and designers with new design ideas without the need for a pre-thought design [18].

Topology optimization explains how the parts that make up the system can form the most appropriate connection. Therefore, topology optimization is the most general description of structural optimization. It is the optimization of the material distribution in order to reach the ideal structure [19].

Optimization models are mathematical expressions that reflect the operation of a system, its properties, and its interaction with the system and other systems around it. The working logic of the optimization is shown below.

$$\begin{cases} max z = f(x,y) \\ k.s. g(x,y) = 0 \\ h(x,y) \leq 0 \\ x \,\mathcal{E}\, \mathcal{R}^n \\ x \,\mathcal{E}\, (0,1,2,\ldots,m) \end{cases} \quad (1)$$

The expression $z = f(x,y)$ specified in Equation 1 represents the objective function, x and y the decision variables, and n the space dimension. In optimization problems, it is aimed to find x and y values that will maximize the $z = f(x,y)$ function. The system properties are determined by the $g(x,y)$ and $h(x,y)$ constraints.

Leaf springs are used in the front and rear hangers of trucks carrying cargo and are made of spring steel. They differ in size and are formed by placing llama-shaped pieces on top of each other. The parts are connected to each other with the help of a center bolt. Hair clamps or special covers are used so that the springs do not fall apart. Spring connection eyes are formed by bending both ends of the main leaf. Leaf springs are attached to the front axle and the bridge with U-bolts. During spring, the spring leaves slide over each other by rubbing. In order to minimize friction, friction-reducing elements are placed between the spring leaves.

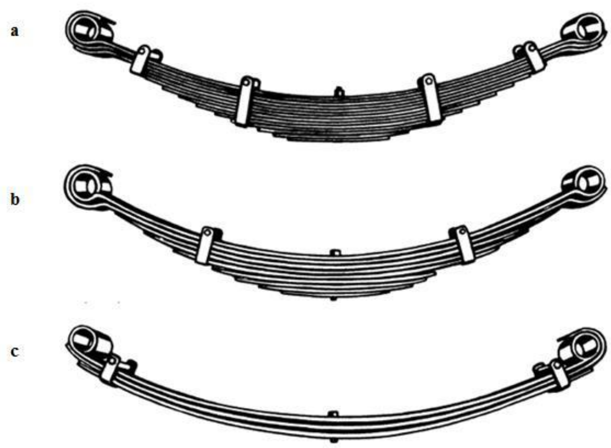

Figure 1. Different types of leaf springs [20].

Leaf spring connection brackets are metal parts that hold and guide the leaf springs connected to the chassis of the vehicle. These brackets are considered an essential component of the vehicle's suspension system. It is designed to direct the forces transferred between the vehicle's chassis and the leaf springs while driving. These brackets allow the leaf springs to bend and absorb shocks during collisions. The visuals of the leaf spring connection brackets designed in different structures are shown in Figure 2. Connection types of leaf spring connection brackets differ according to the function and design of the bracket. Different link types affect suspension system performance and can increase or decrease vehicle mobility. Therefore, leaf spring attachment brackets must be designed with the correct attachment type to optimize vehicle performance.

Figure 2. Various leaf spring attachment brackets.

2.1. Modelling of Leaf Spring Brackets

Leaf Spring Bracket materials suitable for the topology have been considered in the literature and are commonly used in production. By making optimization, modeling was done on two structures. Static analyzes of the leaf spring bracket structure of these two structures, one of which was designed according to the welded and the other casting method, were made by the finite element method.

Modeling of various designs of these leaf spring brackets was done in Catia V6, a package program.

3. Analysis of Leaf Spring Brackets

Static analyzes of the leaf spring bracket structure, designed according to the welded and casting method, were carried out with the finite element method.

ANSYS software was used in these analyses. In this study, the welded model prepared for the analysis was connected to the program used and divided into 83468 medium-quality tetrahedral elements, and 191561 nodes were created to solve the equations of these elements.

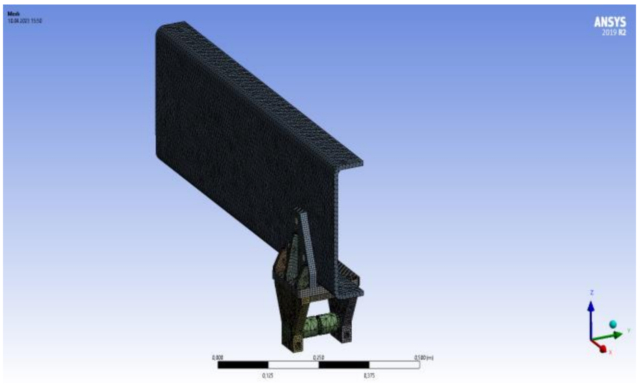

Figure 3. Meshed model for the welded bracket

In the cast model, 157337 medium-quality tetrahedral elements were separated and 264178 nodes were formed to solve the equations of these elements.

In the topology-optimized cast bracket, 289737 medium-quality tetrahedral elements were separated and 481543 nodes were formed to solve the equations of these elements. Figure 3 shows the image of the meshed model for the welded bracket.

Figure 4 shows the image of the meshed model for the casting bracket

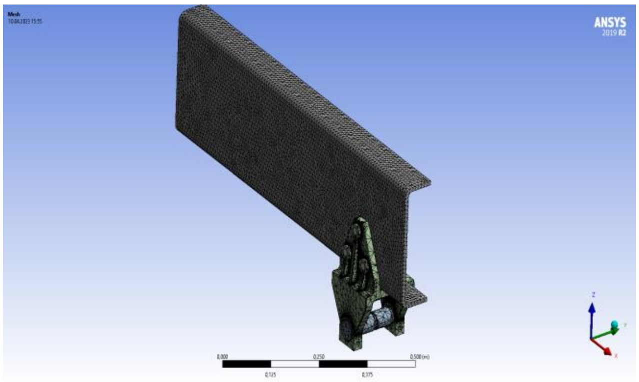

Figure 4. Meshed model for the casting bracket

In order to decide on the number of mesh elements and the accuracy of solving this task, care has been taken to ensure that the difference between the obtained analysis results and the result obtained as a result of increasing the number of mesh elements is less than 5%. It was determined that the number of elements responsible for this difference was sufficient and finite element analysis was performed on this network model.

In addition to the leaf spring connection bracket examined during the analysis, the chassis arm to which the bracket is mounted was modeled together and included in the analysis model by meshing in the same way. Figure 5 shows the image of the meshed model for the topology-optimized cast bracket.

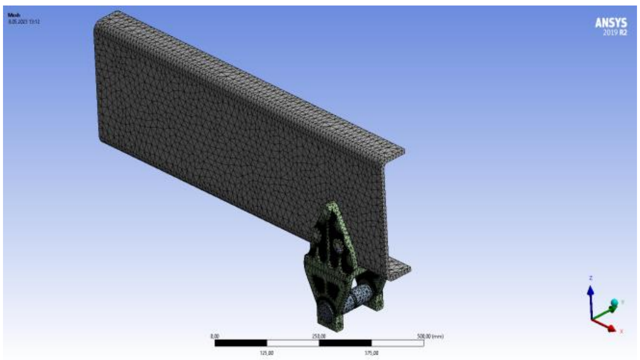

Figure 5. Meshed model for topology-optimized cast bracket

While performing the analysis, the leaf spring connection bracket was fixed to the chassis arm and placed. The load on the leaf spring connection bracket is applied as a point. The load applied as a point is shown in Figure 6.

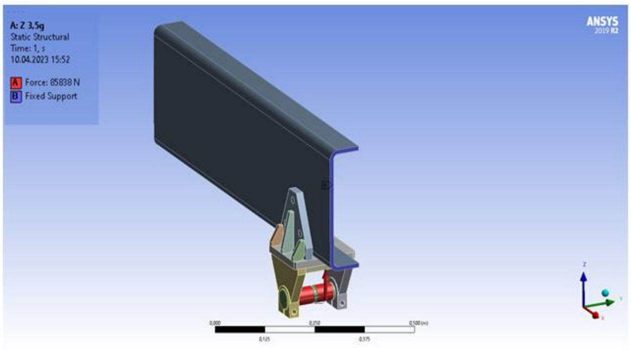

Figure 6. Display of applied load as points

3.1. Static Analysis of Leaf Spring Connection Bracket

After the Finite Element model is created, the limits of the loads that will come to the bracket must be determined to statically examine the leaf spring connection bracket.

Considering that the total weight of the vehicle is 40000 kg, the load per axle in a 4-axle vehicle will be 10000 kg. There are 2 wheels on each axle and there are 2 connection brackets on each wheel side. In this direction, the load per bracket becomes 2500 kg. The bracket carries loads in the Y and Z directions relative to the vehicle axis and has free movement in the X direction. The following loads will be applied while performing the analyses.

- 3.5 g load is acted in the Z direction: 3.5x2500x9.81 = 85837.5 N (Sudden Braking Condition)

3.2. Static Analysis of Welded Bracket

The stress distribution in the welded bracket in the sudden braking scenario is shown in Figure 7.

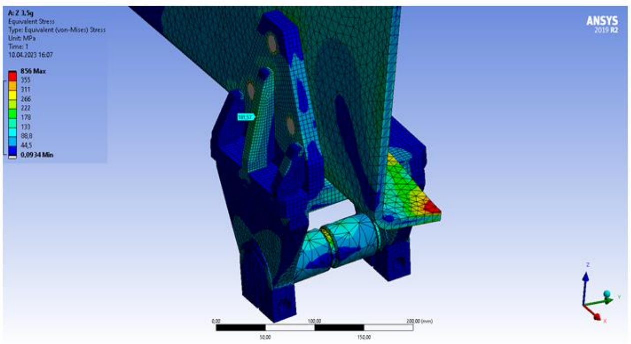

Figure 7. Stress distribution of the welded bracket in the Braking scenario

When the static analysis results of the welded bracket are examined, it is seen that the stresses in the weld regions and joints are locally higher than the other parts of the bracket. Although high stresses are expected in the weld zones of the main structure and support plates, this effect is expected to be minimal. For this purpose, the size and type of weld can be changed to reduce weld weakness.

When the Sudden Braking scenario is examined, the stress distribution is shown in Figure 7. The highest stress revealed in the welded bracket is 181.57 MPa.

3.3. Static Analysis of Casting Bracket

When the static analysis results of the cast bracket are examined, it is seen that the stresses in the radius regions are locally higher than the other parts of the bracket.

Although high stresses are expected in the radius regions of the main structure and support plates, this effect is expected to be minimal. For this purpose, the size of the radius can be changed to reduce the radius weakness.

Figure 8 shows the stress distribution in the cast bracket in the sudden braking scenario.

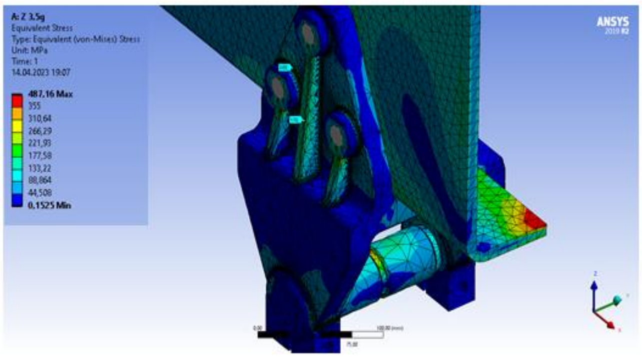

Figure 8. Stress distribution of the cast bracket in the Braking scenario

When the Sudden Braking scenario is examined, the stress distribution is shown in Figure 8. The highest stress released in the cast bracket is 289 MPa.

The yield strength of GGG60 material is 370 MPa. Based on this information, the cast bracket has a safety factor of 1.28 for sudden braking scenarios. According to the static analysis results, it was concluded that the cast bracket is safe in terms of structural strength.

The yield strength of St52 material is 355 MPa. Based on this information, the welded bracket has a safety factor of 1.96 for sudden braking scenarios. According to the results of the static analysis, it was concluded that the welded bracket is safe in terms of structural strength.

3.4. Static analysis of topology-optimized the cast bracket

When the static analysis results of the topology-optimized cast bracket are examined, it is seen that the stresses in the radius regions are locally higher than the other parts of the bracket. Although high stresses are expected in the radius regions of the main structure and support plates, this effect is expected to be minimal. For this purpose, the size of the radius can be changed to reduce the radius weakness.

Figure 9 shows the stress distribution in topology-optimized the cast bracket in the sudden braking scenario.

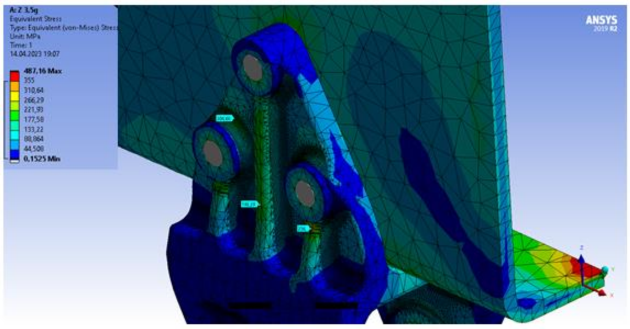

Figure 9. Stress distribution of the cast bracket in the Braking scenario

After performing the topology optimization, the stress distribution is shown in Figure 9 when the sudden braking scenario is examined in the Cast bracket. The highest stress revealed in the cast bracket is 236 MPa. The yield strength of cast bracket GGG60 material is 370MPa. After topology optimization, it has a factor of safety of 1.57 for the sudden braking scenario of the cast bracket.

Thus, when the sudden braking scenario in the cast bracket is examined as a result of the topology optimization, the factor of safety that was 1.28 before the topology optimization increases to 1.57.

4. Conclusions

In this study, the most suitable material for the alternative leaf spring brackets developed for the commercial vehicle suspension system was determined by the optimization method. Welded and cast leaf spring brackets were evaluated. St52 material was chosen for welded leaf spring bracket and GGG60 material was chosen for cast leaf spring bracket. Modeling of these two bracket structures was carried out with the Catia V6 program. Static analyzes were carried out in different scenarios in order to evaluate the resistance of the leaf spring connection bracket. Static analyzes of the leaf spring bracket structure, designed according to the welded and casting method, were carried out with the finite element method by using ANSYS software. When the Sudden Braking scenario is examined, the highest stress revealed in the welded bracket is 181.57 MPa and The highest stress released in the cast bracket is 289 MPa. The yield strength of GGG60 material is 370MPa. Based on this information, the cast bracket has a safety factor of 1.28 for sudden braking scenarios. The yield strength of St52 material is 355MPa. Based on this information, the welded bracket has a safety factor of 1.96 for sudden braking scenarios. According to the results of the static analysis, it was concluded that the welded bracket is safe in terms of structural strength. After static analysis of topology-optimized the cast bracket, the sudden braking scenario is examined in the Cast bracket. The highest stress revealed in the cast bracket is 236 MPa. As a result of the topology optimization, stress was reduced by 18% and the safety factor increased to 1.57. This resulted in a safety factor increase of approximately 23%.

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