Research Article
Ziraat Mühendisliği (379), 25-34
DOI: 10.33724/zm.1402086

Stress Analysis of Modern Leaf Springs Made by Different Materials for New Agricultural Trolleys

Yeni Tarım Arabaları için Farklı Malzemelerden Yapılan Modern Yaprak Yayların Gerilme Analizi

Abstract

Tractors can be used in a variety of agricultural operations that require towing. All these transportation tasks are now carried out in mechanized enterprises using trolleys attached to the back of the tractor. In practice, transport conditions vary significantly depending on the product. Because of this reason, nowadays the design properties of tractor trolleys with different capacities change with technological advances in material science and carrying requirements, as well as weight carry needs in agricultural applications. Today, computer-aided design has become an integral part of computer-aided engineering and has made it possible to evaluate many materials before production with the finite element analysis methodology. Because of this reason, the focus of this technical research was on the new leaf spring properties based on steel, steel alloy, and carbon steel materials manufactured using modern methods. One of the main uses of tractors in agriculture is pulling. In practice, pulling not only agricultural machines but also various types of agricultural trolleys that are indispensable for agricultural enterprises is an important area of use. Conditions such as carrying weight in agricultural trolleys vary depending on the purpose of use and their designs are also different. For this reason, determining the properties of new leaf springs based on steel, steel alloy, and carbon steel materials produced using modern methods and more suitable for today's agricultural conditions and heavy-

Sorumlu Yazar
Abdullah BEYAZ[1]
abeyaz@ankara.edu.tr
0000-0002-7329-1318

Yazar
Veysel GÜL[2]
veysel.gul@ahievran.edu.tr
0000-0002-9345-8613

1 Ankara Üniversitesi Ziraat Fakültesi Tarım Makinaları ve Teknolojileri Mühendisliği Bölümü

2 Kırşehir Ahi Evran Üniversitesi

Gönderilme Tarihi : 08 Aralık 2023
Kabul Tarihi : 24 Nisan 2024

weight trolleys is the focus of this study. According to the results obtained from steel, steel alloy, and carbon steel materials for 20- and 40-tons carrying capacities, it is found that the maximum Von Mises stress is 5868.48 MPa under 200000 N load for carbon steel material, also the maximum displacement is 15.4907 mm under 200000 N load for carbon steel material and maximum safety factor under 15 ul 200000 N load for all materials. Additionally, under 100000 N, the order of carbon steel and steel alloy displacement values are different from the regular behaviour of the materials order. Computer-aided design and analysis revealed modern leaf springs based on the increase in the carrying weight requirements of agricultural carrying applications. So, based on the results carbon steel material is the last material to be evaluated among all evaluated materials for the modern leaf springs production for agricultural trolleys.

Keywords: Leaf springs, tractor trolleys, modern steel materials, CAD, computer aided analysis

Özet

Traktörler, çeki gerektiren çeşitli tarımsal işlemlerde kullanılabilmektedir. Tüm bu taşıma işleri artık mekanize işletmelerde, traktörün arkasına takılan arabalar kullanılarak gerçekleştirilmektedir. Uygulamada taşıma koşulları ürüne bağlı olarak önemli ölçüde değişiklik göstermektedir. Bu nedenle günümüzde farklı taşıma kapasiteli tarım arabalarının tasarım özellikleri, malzeme bilimindeki teknolojik gelişmeler, taşıma gereksinimleri ve tarımsal uygulamalardaki ağırlık taşıma ihtiyaçları ile değişmektedir. Günümüzde bilgisayar destekli tasarım, bilgisayar destekli mühendisliğin ayrılmaz bir parçası haline gelmiş ve sonlu elemanlar analiz metodolojisi ile birçok malzemenin üretim öncesinde değerlendirilmesine olanak sağlamıştır. Bu nedenle, bu teknik araştırmanın odak noktası, modern yöntemler kullanılarak üretilen çelik, çelik alaşımı ve karbon çeliği malzemelerine dayalı yeni yaprak yay özellikleridir. Tarımda traktörlerin ana kullanım alanlarından biri çekme işidir. Uygulamada sadece tarım makinelerinin değil, tarım işletmelerinin vazgeçilmezi olan çeşitli tiplerdeki tarım arabalarının da çekilmesi önemli bir kullanım alanıdır. Tarım arabalarında ağırlık taşıma gibi koşullar kullanım amacına göre değişmekle birlikte tasarımları da farklılık göstermektedir. Bu nedenle modern yöntemlerle üretilen ve günümüz tarım koşullarına daha uygun olan 20 – 40-ton taşıma kapasiteleri için çelik, çelik alaşımı ve karbon çeliği malzemelerden üretilen yeni yaprak yayların ve ağır yük arabalarının özelliklerinin belirlenmesi bu çalışmanın odak noktasını oluşturmaktadır. Çelik, çelik alaşımı ve karbon çeliği malzemelerden elde edilen sonuçlara göre karbon çeliği malzeme için maksimum Von Mises geriliminin 200000 N yük altında 5868,48 MPa olduğu, karbon çeliği malzeme için ise maksimum yer değiştirmenin 200000 N yük altında 15,4907 mm olduğu bulunmuştur. Tüm malzemeler için karbon malzeme ve 200000 N yük altında maksimum güvenlik faktörü 15 ul olarak bulunmuştur. Ek olarak, 100000 N'un altında karbon çeliği ve çelik alaşımının yer değiştirme değerlerinin, malzeme sırasının normal davranışından farklı olduğu görülebilir. Bilgisayar destekli tasarım ve analiz, tarımsal taşıma uygulamalarının taşıma ağırlığı gereksinimlerinin artmasına bağlı olarak modern yaprak yayları ortaya çıkmıştır. Dolayısıyla, tarım arabaları için modern yaprak yay üretimi için değerlendirilen tüm malzemeler arasında karbon çeliği malzemenin değerlendirilecek son malzeme olduğu sonucuna varılmıştır.

Anahtar Kelimeler: Yaprak yaylar, tarım arabası, modern malzemeler, CAD, bilgisayar destekli analiz

Introduction

Transportation is moving material from one location to another without altering the original structure. In the past, man would either do the heavy lifting or rely on animals to transport their food, water, shelter materials, and fuel over long distances. Changes in human society directly result from the era's prolific creativity and discovery. Meanwhile, many researchers have worked on the increasingly pressing issue of transportation, leading to the creation and widespread use of transport vehicles that can be towed both by their motor and by motor vehicles (Kadayıfçılar, 1993).

Both the theory and practice of transportation in the agricultural sector differ significantly from their counterparts in the business world. For this reason, studying agricultural transportation and the vehicles used for it is both important and necessary. The agriculture sector requires a great deal of time for the transportation of products from the field to the operating center, the market, the mill, the bringing of fuel oil to the operating center, the transportation of fertilizer to the field, transportation of animals, animal products, and feed, transportation of workers to the field, etc. These transportation tasks are now easy by tractors with trolleys attached to the back. These trolleys are double-duty vehicles, transporting tools and machinery for agriculture in both directions within the business. Tractors with trolleys attached have thus become an increasingly important part of modern farming. The need for tractors and other tillage, cultivation, and transportation machinery is rising as agricultural yields improve in developing nations. The demand for tractor trolleys and simple loaders rises in tandem with the increasing efficiency of the transportation market.

Most agricultural products transported by trolleys are perishable and contain water. Tractor trolleys and crates range in size, construction, and design because agricultural products have widely varying densities. These products that require transportation can be categorized into six broad categories.

1. Cereals, flour, bulgur, and other mill products; animal feeds, etc.

2. Veggies, fruits, sugar beet pulp, and other plant-based foods, roots, and tubers.

3. Grass hay, other fibers, and other green fodder.

4. Compost, chemical fertilizers, pesticides, soil amendments (like lime), and fossil fuels are all examples of four (wood, and ember products).

5. Liquids (milk, wine, water, fuel, urine, etc.)

6. Products and components are not covered by the first five categories (Kadayıfçılar, 1993).

Based on material properties carried on the tractor trolleys, design parameters and properties of each part are important for tractor-trolley production. Because of this reason, a lot of researchers and engineers focused on the leaf spring design and analysis, so they share a lot of valuable research in the literature. For example, Krishan and Aggarwal (2012) worked on a finite element approach for the analysis of a multi-leaf spring using Computer-Aided Engineering (CAE) tools. They claimed that computer-aided engineering tools are being used to assess the durability and functionality of parts and assemblies. They also imply that engineering boundary value problems can be approximatively solved using a computing method called finite element analysis (FEA).

Leaf springs for vehicles were analyzed and compared using E-glass/epoxy and steel 65Si7 in a study by Shakti (2017). He seems to be suggesting that a comparison of composite and steel leaf springs in terms of load capacity, weight, and stiffness effectiveness is in the works. Furthermore, he emphasized stresses and deflections as design imperatives, as well as the measurements of a modern ordinary steel leaf spring of a light business vehicle.

The leaf spring is used in tractor-trailers without much technical and economic consideration, as pointed out by Dhoshi et al. (2011). They stress that there are opportunities to increase product quality while keeping costs low in the current work environment. They also imply that the design process is a key area for maximizing product quality while minimizing expenses. Additionally, they stress that it is possible to design a product so that it outperforms competitors' offerings at a lower cost to the consumer. The design strategy is decided upon in light of mass production, while the material and manufacturing process are chosen in light of cost and strength considerations.

In recent years, with increasing competition and developing technology, heavy vehicles used for transportation in the agricultural industry have aimed to absorb more loads in many sub-parts under the chassis. The fact that the unit part weight of the conventional type of leaf springs in the wheel suspension system of heavy vehicles is higher than that of parabolic leaf springs has led to an increase in the production of parabolic leaf springs. Transportation conditions vary widely from one product to the next. For this reason, tractor trolleys' parts design properties evolve alongside advances in materials science and the evolving demands of agricultural transport. Therefore, this study focuses on determining attributes of recently developed leaf springs made of cutting-edge materials. With the aid of computer-aided design and analysis, an increase in the load requirements of agricultural applications was also detected.

Material and Method

Material

The French word 'Remorque' and the German word 'Traktorrolle' are both translations of, 'tractor trolleys' which are used here (Figure 1). When it comes to providing transportation services for agricultural businesses, the tractor-trolley is a vehicle whose maximum speed and driving style are restricted by Turkish laws (Kadayıfçılar, 1993). Therefore, a wheeled vehicle capable of traveling between 20 and 40 km h^{-1} that is towed by an agricultural tractor and used in the transportation of products and other materials produced in agricultural enterprises or to be transported to the enterprise, as well as the transportation of people for agricultural enterprises (Anonymous, 2024).

There are two types of tractor trolleys: those designed for general use, and those designed for a specific task. Small farms can save money by using multipurpose tractor trolleys. More than one tractor-trolley may be needed for larger operations. Still, the financial case favors using both vehicles for general transportation even in this scenario within the realm of private and specialized conditions.

Figure 1. Tractor trolley (Anonymous, 2023a)

Method

General tractor-trolley parts construction and related features

It is preferable, when transporting via tractor trolley, to move as much usable goods as possible while keeping the trolley weight to a minimum. This possibility has been brought to a very satisfying level thanks to the use of high-quality materials in the construction of tractor trolleys on the one hand, the improvement of construction methods, and the introduction of new trolley types on the other. For a long time, intrinsic weight and useful load were roughly equivalent. But as the trolley's carrying capacity grows, the ratio of transportation costs to acquisition costs reaches a more reasonable level. Agricultural transport productivity also rises alongside increases in trolley capacity and the pulling power of tractors. The use of heavy-duty tractor trolleys, however, is fraught with challenges in daily operations. Therefore, maximum-capacity 40-ton trolleys are preferred in both construction and use nowadays. Because of all these factors, the tractor-trolley is an all-encompassing subject in terms of its construction, operation, and environmental factors.

Tractor-trolley design features are important for the benefit of tractor-trolley manufacturers the reduction of wasteful materials, and the actualization of export opportunities. As was previously mentioned, trailers must already comply with standards confirmed by long experience in the manufacturing process to ensure safe transportation. This problem's salient features are summed up as follows: In general, the trolley and all its components must be sturdy enough to support the heaviest load possible.

Türkiye for the agricultural trolley production quality focuses on some regulations like European Union parliament regulation for agricultural or forestry tractors, their trailers No. 2003/37/EC, TS 3414 Water tankers used in agriculture (Anonymous, 2023b; EU, 2003). Therefore, it is helpful to standardize the material and its dimensions for use in trolley construction. Because of this reason, a well-designed suspension system will keep you at a pleasant pace, make it easier to make sharp turns, boost passenger comfort, and lessen tire wear on tractors' trolleys.

Characteristics of Tractor Trolleys

Together, a tractor and its accompanying trolley provide the most efficient and flexible service possible with capacities ranging from under 0.75 tonnes up to 40 tonnes. The combination of a tractor and a trolley is considered a transport within modern agricultural mechanization practices and provides advantages in many contexts. As can be seen, then, leaf springs serve a variety of purposes on various tractor trolleys.

Design of the leaf spring

Flat springs, or leaf springs, are made from flat metal plates (Figure 2). The two primary configurations of leaf springs are: The first multi-leaf and second mono-leaf springs' primary function is to absorb shocks, but they also must deal with other loads, such as those caused by bumps in the road, braking, driving, etc. As opposed to the mono-leaf spring, which consists of a single steel plate, the multi-leaf spring is constructed from a stack of steel plates of varying lengths. The spring compresses to dampen vibrations caused by bumps in the road. The suspension movement is made possible by the leaf springs' ability to flex and slide against one another (Ravindra et al., 2014).

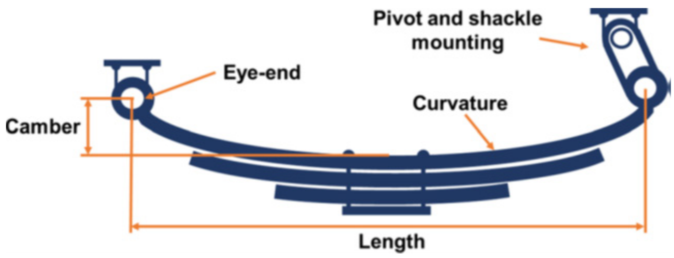

Figure 2. Semi-elliptic leaf spring components (Gaylo et al., 2020)

Steel leaf springs made from steel, steel alloy, and carbon steel material are produced by a wide variety of businesses, and they find widespread application in the creation of both parabolic leaf springs and conventional multi-leaf springs. By deflecting, the leaf spring stores the potential energy caused by vertical vibrations, shocks, and bumps (caused by road irregularities) and gradually releases it. Suspension comfort is guaranteed by a system that can absorb and store a lot of strain energy (Ravindra et al., 2014).

The design can be broken down into three broad classes: (I) constant thickness and width; (II) constant thickness and varying width; and (III) varying width and varying thickness (Kueh and Faris, 2012). An essential design consideration for a leaf spring is that its flexural rigidity should increase from the spring's ends toward its middle. These include designs with a constant cross-section, a constant width with a variable thickness, and a constant thickness with a fixed width. For ease of mass production and to permit continuous reinforcing of fibers, a constant cross-section design has been chosen. The original three-leaf steel spring on a tractor trolley inspired the design of this leaf spring. Leaf springs consist of a series of leaves. The length of the leaves varies. The leaves are usually given an initial curvature or are cambered so that they tend to flatten under load. The longest leaf has eyes at the ends. These leaves are called the main leaves, and the other leaves are called graduated leaves. All blades are connected using steel straps. The length of the longest blade used in the study is 1072 mm. The length of the other leaves is 890 and 668 mm respectively. The size of the lower flap used at the bottom of the spring is 100x60 mm. Steel rebound clamps of 72x30 mm are designed to connect the leaf springs. The thickness of all parts used is planned as 8 mm. Properties of materials used in leaf spring design can be seen in Table 1. The leaf spring designs were modelled and analyzed in Autodesk Inventor Pro with Nastran In-CAD (under educational license).

Table 1. Properties of materials used in leaf spring design

Material	Young's Modulus (GPa)	Poisson's Ratio	Density (g/cm³)
Steel	210.000	0.30	7.850
Steel Alloy	205.000	0.30	7.730
Carbon Steel	200.000	0.29	7.850

The specifications are assumed to be the same as those for a steel leaf spring. The design parameters used as, W = 100000 N, and 200000 N is the design load (Figure 3).

Figure 3. Leaf spring model with load for computer-aided stress analysis

Results and Discussion

The results of the Von Mises stress, displacement, and safety factor results of steel, steel alloy, and carbon steel materials under 100000 N, and 200000 N loads can be seen in Figure 4-9. Also, the results summaries are presented in Table 2-8.

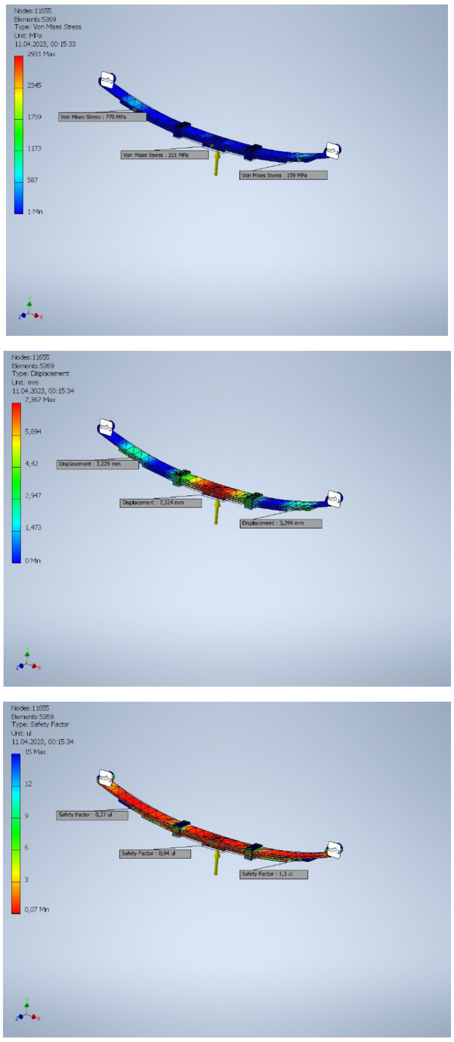

Figure 4. Von Mises stress, displacement, safety factor results of steel material under 100000 N load

Table 2. Von Mises stress, displacement, and safety factor result summary of steel material under 100000 N load

Name	Minimum	Maximum
Volume	1510790 mm^3	
Mass	11.8597 kg	
Von Mises Stress	0.537622 MPa	2930.89 MPa
1st Principal Stress	-442.677 MPa	1048.93 MPa
3rd Principal Stress	-3288.06 MPa	110.341 MPa
Displacement	0 mm	7.3669 mm
Safety Factor	0.070627 ul	15 ul

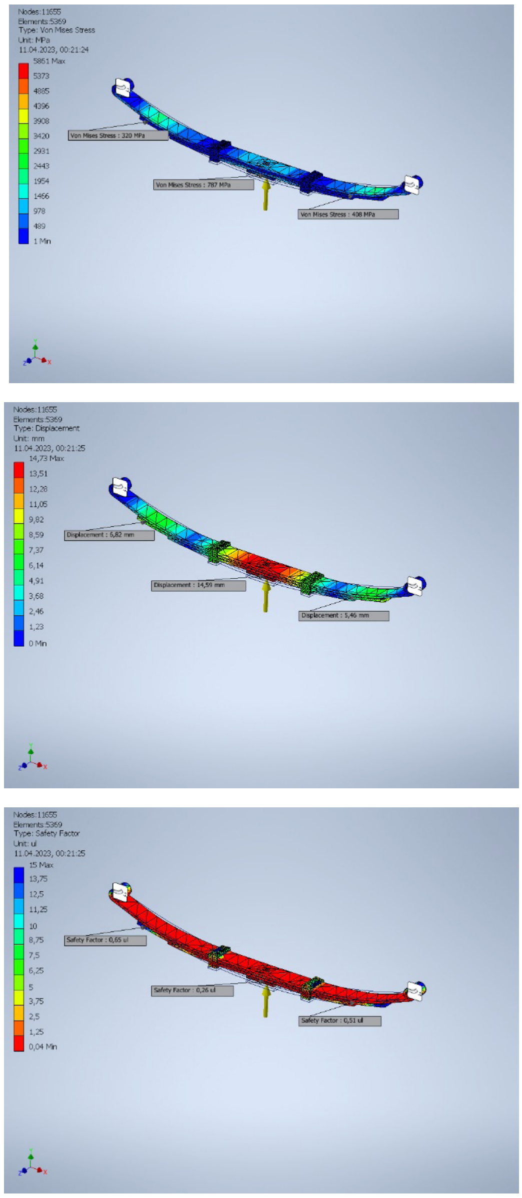

Figure 5. Von Mises stress, displacement, safety factor results of steel material under 200000 N load

Table 3. Von Mises stress, displacement, and safety factor result summary of steel material under 200000 N load

Name	**Minimum**	**Maximum**
Volume	1510790 mm^3	
Mass	11.8597 kg	
Von Mises Stress	1.06523 MPa	5861.25 MPa
1st Principal Stress	-885.415 MPa	2097.99 MPa
3rd Principal Stress	-6575.86 MPa	220.679 MPa
Displacement	0 mm	14.7338 mm
Safety Factor	0.0353167 ul	15 ul

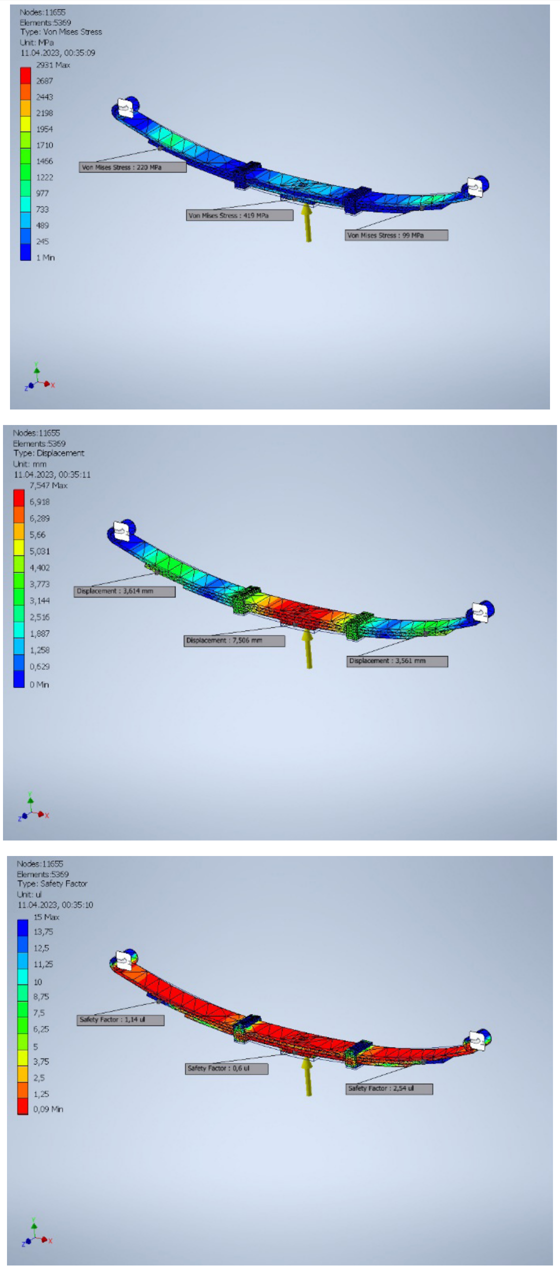

Figure 6. Von Mises stress, displacement, safety factor results of steel alloy material under 100000 N load

Table 4. Von Mises stress, displacement, and safety factor result summary of steel alloy material under 100000 N load

Name	**Minimum**	**Maximum**
Volume	1510790 mm^3	
Mass	11.6784 kg	
Von Mises Stress	0.542132 MPa	2930.9 MPa
1st Principal Stress	-442.662 MPa	1048.93 MPa
3rd Principal Stress	-3288.11 MPa	110.336 MPa
Displacement	0 mm	7.54665 mm
Safety Factor	0.085298 ul	15 ul

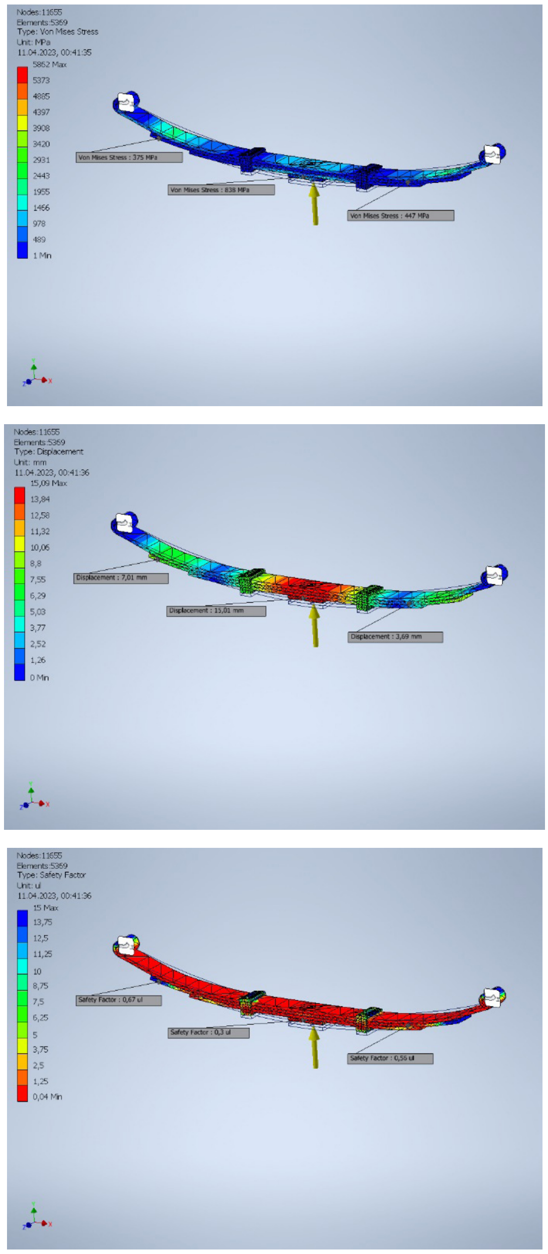

Figure 7. Von Mises stress, displacement, safety factor results of steel alloy material under 200000 N load

Table 5. Von Mises stress, displacement, and safety factor result summary of steel alloy material under 200000 N load

Name	Minimum	Maximum
Volume	1510790 mm³	
Mass	11.6784 kg	
Von Mises Stress	1.08421 MPa	5861.8 MPa
1st Principal Stress	-885.325 MPa	2097.87 MPa
3rd Principal Stress	-6576.22 MPa	220.672 MPa
Displacement	0 mm	15.0933 mm
Safety Factor	0.042649 ul	15 ul

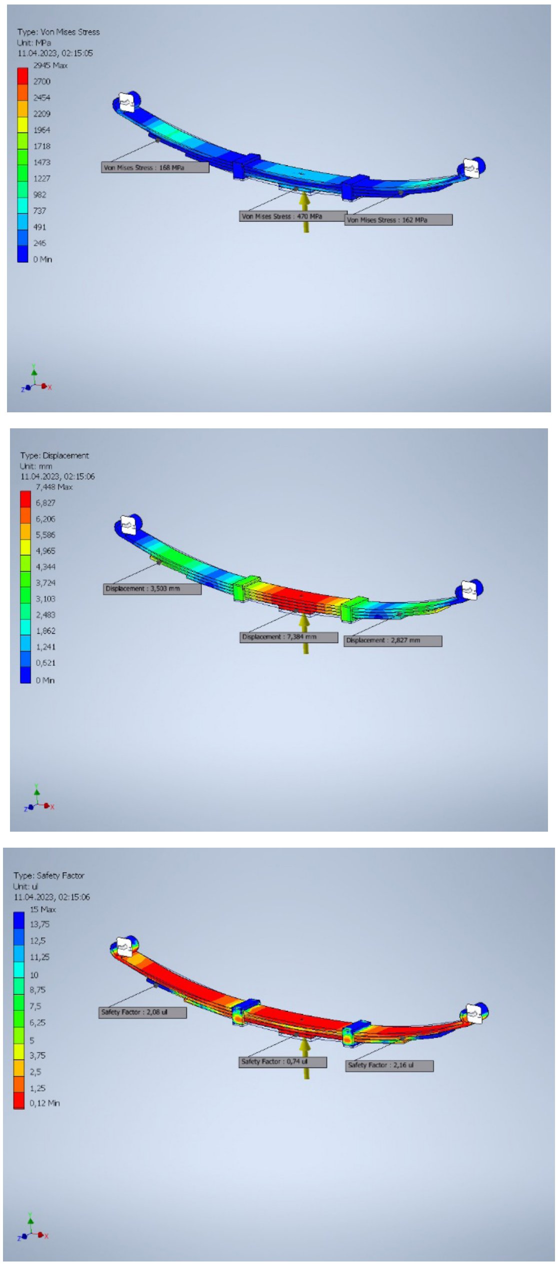

Figure 8. Von Mises stress, displacement, safety factor results of carbon steel material under 100000 N load

Table 6. Von Mises stress, displacement, and safety factor result summary of carbon steel material under 100000 N load

Name	Minimum	Maximum
Volume	1510790 mm³	
Mass	11.8597 kg	
Von Mises Stress	0.392285 MPa	2945.15 MPa
1st Principal Stress	-410.984 MPa	1080.52 MPa
3rd Principal Stress	-3278.8 MPa	105.68 MPa
Displacement	0 mm	7.44764 mm
Safety Factor	0.118839 ul	15 ul

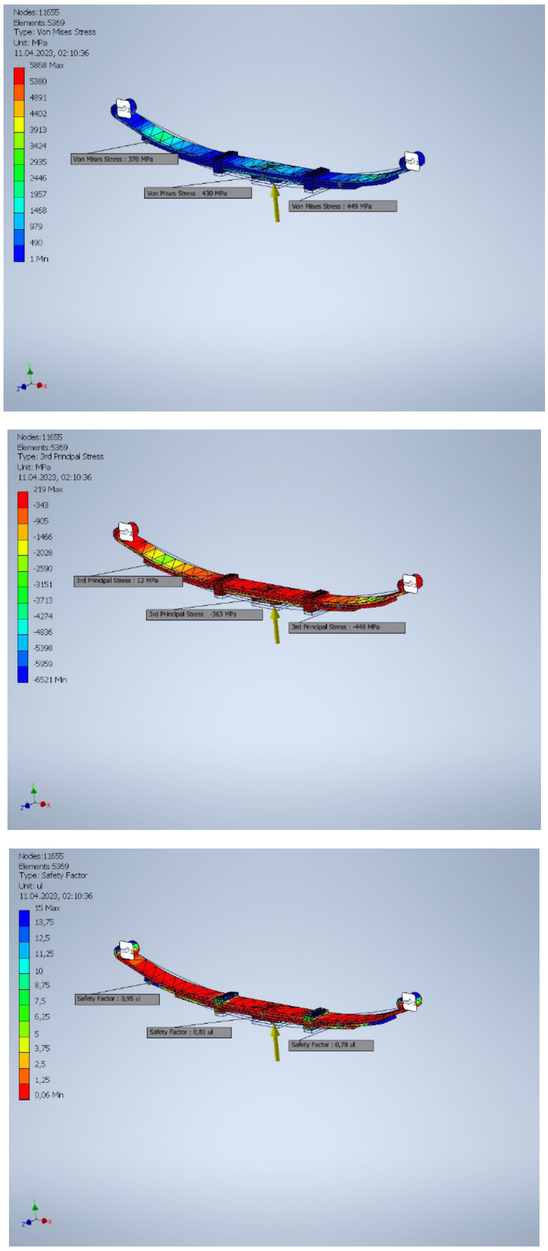

Figure 9. Von Mises stress, displacement, safety factor results of carbon steel material under 200000 N load

Table 7. Von Mises stress displacement and safety factor result summary of carbon steel material under 200000 N load

Name	Minimum	Maximum
Volume	1510790 mm^3	
Mass	11.8597 kg	
Von Mises Stress	1.05208 MPa	5868.48 MPa
1st Principal Stress	-818.745 MPa	2094.67 MPa
3rd Principal Stress	-6520.81 MPa	218.561 MPa
Displacement	0 mm	15.4907 mm
Safety Factor	0.0596407 ul	15 ul

According to the results of steel, steel alloy, and carbon steel materials, it is found that the maximum Von Mises stress is 5868.48 MPa under 200000 N load for carbon steel material, also maximum displacement 15.4907 mm under 200000 N load for carbon steel material and maximum safety factor under 15 ul with200000 N load for all materials. Additionally, it can be seen that under 100000 N the order of carbon steel and steel alloy is different from the regular behaviour of the materials order table (Table 8).

Table 8. Von Mises stress and displacement result summary of all materials under all load

Von Mises Stress (MPa)	Load (N)	Material	Displacement (mm)	Load (N)	Material
2930,89	100000	Steel	7.3669	100000	Steel
2930.90	100000	Steel Alloy	7.54665	100000	Carbon Steel
2945.15	100000	Carbon Steel	7.44764	100000	Steel Alloy
5861.25	200000	Steel	14.7338	200000	Steel
5861.80	200000	Steel Alloy	15.0933	200000	Steel Alloy
5868.48	200000	Carbon Steel	15.4907	200000	Carbon Steel

In some related literature important results are presented about this issue, for example, Dhoshi et al. (2011), findings highlight the need for both macro and micro-level analysis. They used ANSYS 11.0 software to perform Finite Element Analysis (FEM), and their research highlights the value of stress analysis. Bringing the total number of leaf springs down from 17 to 13 will save about 6 kg of weight and nearly 20% of the manufacturing cost. This study emphasizes the importance of FEM for businesses of all sizes, as it can help cut costs and boost precision.

Shokrieh et al. (2003) compared the composite leaf spring optimized by the FEM with the steel leaf spring and emphasized that they obtained lower stresses in the composite leaf spring. Mouleeswaran et al. described the static and fatigue analysis of steel leaf springs and composite multi-leaf springs composed of glass fiber-reinforced polymer using life data analysis (Kumar and Vijayarangan, 2007). Strzt and Paszek (1992) carried out a three-dimensional contact analysis of a car leaf spring in their research. In the research, they tried to determine the static three-dimensional contact problem of the leaf spring by the FEM. As a result of the research, the maximum displacement of the spring was selected as the reliability criterion.

Krishan and Aggarwal (2012) used FEM and CAE tools to design and analyze the stress and deflection of a multi-leaf spring (i.e. CATIA, ANSYS). Results from the FEA and experiments show that the leaf spring deflects by 0.632% at full load and by the same amount at half load, respectively, proving the accuracy of the model and analysis. The bending stress is also very close to the experimental results in both cases. Maximum equivalent stresses are less than the material's yield stress, so the design is safe from failure.

One advantage of this study is that it sheds light on the efforts made by the agricultural manufacturing sector to strengthen and lighten their products. Also, leaf springs are built to dampen vertical vibrations caused by potholes and other road hazards. Additionally, they are much lighter leaf springs. Because of the modern material's internal damping, vibration energy is absorbed more effectively within the material, reducing the amount of noise transmitted to nearby structures.

Conclusion

Transportation mechanization is significantly impacted by the scale of the business. The tractor and trolley combination is used by small and medium-sized businesses, while large businesses typically use either a larger combination. The growing prevalence of mechanized farming transportation has broad justification in the field of agricultural mechanization. Because it enhances productivity, increases output, and decreases expenses. Mechanized transportation can be made even more effective with optimum transportation processes.

For the benefit of future agricultural trolleys, this research aims to provide a stress analysis of contemporary leaf springs manufactured from various materials based on CAD, CAE, and FEM. As a result, the characteristics of state-of-the-art leaf springs were the primary focus of this research, it showed that using CAD, CAE, and FEM evaluations gave us very valuable information about designed models and material behaviours.

Authors' Contributions

All authors contributed equally to the article.

Conflicts of Interest Statement

The authors declare that they have no conflicts of interest.

References

Anonymous, (2024). Legal Speed Limits That Vehicles Must Follow in Türkiye. https://www.kgm.gov.tr/Sayfalar/KGM/SiteTr/Trafik/HizSinirlari.aspx, Accessed 08 April 2024.

Anonymous, (2023a). 40-ton two-axle back dump trolley. https://tr.made-in-china.com/co_luckinvehicle/product_2-Axles-40-Tons-Side-Wall-Full-Trailer-Box-Stake-Fence-Trailer-Drawbar-Fence-for-Agricultural-Farm-Transport-Cargo-Truck-Trailer-Tractor-Trailer-Full-Trailer_ysnsrsigug.html, Accessed 20 April 2023.

Anonymous, (2023b). Agricultural Water Tanks. TS 3414, Turkish Standards Institute, Ministries, Ankara.

Dhoshi, N.P., Ingole, N.K. and Gulhane, U.D. (2011). Analysis and modification of leaf spring of tractor trailer using analytical and finite element method. *International Journal of Modern Engineering Research*, 1(2): 719-722.

EU, (2003). Directive 2003/37/EC of the European Parliament and of the Council (repealed). https://www.legislation.gov.uk/eudr/2003/37/resources, Accessed 11 March 2024.

Gaylo, R., Farahani, S., Schmueser, D. and Pilla, S. (2020). Optimization of a mono-composite leaf spring using a hybrid fiber-layup approach. *International Journal on Interactive Design and Manufacturing*, 14: 407-421.

Kadayıfçılar, S., (1993). Design Basics of Tractor Trolleys. Ankara University Faculty of Agriculture Publications: 1297, Book No: 373

Krishan, K. and Aggarwal, M.L. (2012). A finite element approach for analysis of a multi leaf spring using CAE tools. *Research Journal of Recent Sciences*, 2277, 2502.

Kueh, J.T.J. and Faris, T. (2012). Finite element analysis on the static and fatigue characteristics of composite multi-leaf spring. *Journal of Zhejiang University Science A*, 13: 159-164.

Kumar, M.S. and Vijayarangan, S. (2007). Analytical and experimental studies on fatigue life prediction of steel and composite multi-leaf spring for light passenger vehicles using life data analysis. *Materials Science*, 13(2): 141-146.

Ravindra, P., Raman, M. and Sanjay, B. (2014). Modeling and analysis of carbon fiber epoxy based leaf spring under the static load condition by using FEA. *International Journal of Emerging Science and Engineering*, 2(4): 39-42.

Shakti, P. (2017). Vehicle Leaf Spring Design, Analysis and Comparison by Using E-Glass/Epoxy and Steel 65Si7. *International Journal of Innovative Science Engineering and Technology*, 4(1): 105-110.

Shokrieh, M.M. and Rezaei, D. (2003). Analysis and optimization of a composite leaf spring. *Composite Structures*, 60(3): 317-325.

Skrtz, A., and Paszek, T. (2003). Three dimensional contact analysis of the car leaf spring. Numerical methods in continuum mechanics, 7(4): 115-124.