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Araştırma Makalesi / Research Article

Topology Optimization of Freight Wagon Chassis Under Multi Loading Conditions

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Abstract

In this study, planning performance values in a freight wagon chassis geometry are discussed. Container-carrying type chassis were preferred as freight wagons, topology optimization, 2020 simulation, was used for the traditional freight wagon for the optimization add-on. 1023 steel material was chosen as the material for the FEA analysis. Within the safety limits required for freight wagons, the traditional freight wagon has been lightened by 14.51 percent. Although the freight wagon was lighter, it gave uniform results in the load distribution, thus reducing the manufacturing costs of a standard freight wagon. The legal load limitations in railway management have been brought to the sum of the wagon weight and the load. Weight improvements in the tare of any freight car mean more loads can be carried. With this study, it has been observed that a conventional freight wagon chassis has a positive effect not only on manufacturing costs but also on operating costs

Keywords: *Finite element analysis, Freight car chassis, Steel, Materials*.

Çoklu Yükleme Koşulları Altında Yük Vagonu Şasisinin Topoloji Optimizasyonu

Öz

Bu çalışmada bir yük vagonu şasi geometrisinde planlama performans değerleri ele alınmıştır. Yük vagonu olarak konteyner taşınabilen tipte şasiler tercih edilmiştir. optimizasyon metodu olarak topoloji optimizasyonu kullanılmıştır. Sonlu elemanlar (FEA) analizi için malzeme olarak 1023 çelik malzeme tercih edilmiştir. Yük vagonları için gerekli güvenlik limitleri dahilinde çalışma sonucunda geleneksel yük vagonunu %14,51 hafifletilmiştir. Yük vagonu daha hafif olmasına rağmen yük dağılımında da düzenli sonuçlar elde edilmiştir böylece standart bir yük vagonunun imalat maliyetleri düşürülmüştür. Demiryolu işletmeciliğinde yasal yük sınırlamaları vagon ağırlığı ve yükün toplamına kadardır. Herhangi bir yük vagonun darasındaki ağırlık iyileştirmeleri daha fazla yük taşınabileceği anlamına gelmektedir. Bu çalışma ile geleneksel bir yük vagonu şasisinin yalnızca imalat maliyetleri değil işletme maliyetlerine olumlu etkisi olduğu gözlemlenmiştir.

Keywords: *Sonlu elemanlar, Analiz, Yük vagonu şasisi, Çelik, Malzeme.*

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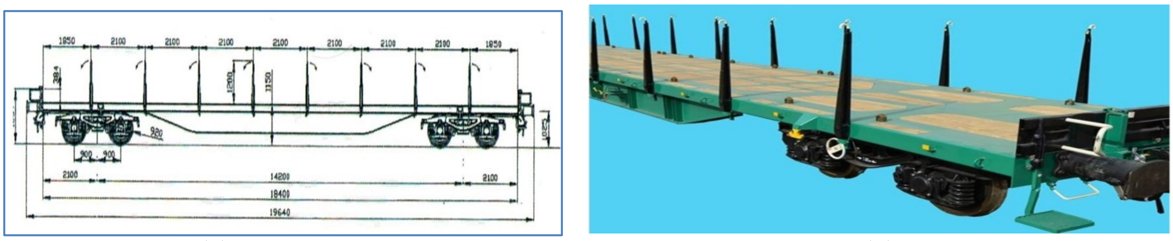
1. Introduction

Railways and freight wagons play an important role in freight transportation. Freight wagons are divided into various classes according to the type of manufacture and the load they carry. Among the freight wagons, the most used ones are the freight wagons that can carry containers. The ability to transport containers by land, sea and rail has made container transportation preferable in international trade. When designing container type freight wagons, they may differ according to the dimensions of the container they will carry and the loading situation. When designing freight wagons, they can be designed to carry only containers or, as seen in Figure 1, they can be designed to carry both containers and block loads such as marble.



(a) (b)

Figure 1. (a) RGNS Freight wagon drawing. **(b)** Image of RGNS Freight wagon.

A designer must consider many parameters when designing a freight car. The designer should primarily design within the dimensions determined by the standards, this is important for the trains to work in harmony. The amount of cargo to be carried by the freight wagon and the type of cargo are other important parameters. The weight of the chassis of the freight wagon is a situation that concerns the operation. There are restrictions on the weight of the freight car and the size of the cargo you will be carrying. The lightness of a wagon reduces its cost and increases the amount of cargo it will carry.

Both manufacturing and operating costs directly affect the weight of the wagon. There are basically two ways to make a wagon lighter, the first is to change the material selection and the second is to optimize the design (Figure 2).

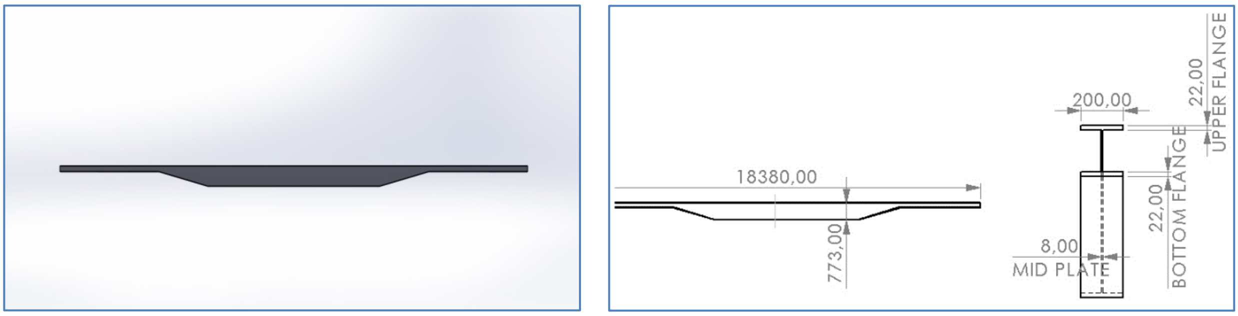
The RGNS wagon is a freight wagon, and the meanings of the letters on the RGNS wagon are as follows, respectively; the letter “R” indicates that the wagon is a normal type bogie platform wagon, “G” and “N” indicates specifies the characteristics of the wagons designed according to the type and characteristics of the load, “S” indicates that the wagon is suitable for speed of 100km/h. and bogies are cars that make the wagons move.

This study is important in terms of showing that the safety factors are very high in the railway industry. With the development of steel manufacturing technologies, the amount of unpredictable defects in steel has decreased considerably. Our study is important in terms of showing the advantages of optimization studies and lightweight designs with lower safety numbers to freight wagon management. Our study is innovative in terms of showing the advantages of optimization studies and lightweight designs with lower safety numbers to freight wagon management. With the increase in optimization studies, it is thought that conventional wagon designs will be replaced by modern designs.

2. Materials and Methods

In this study, RGNS type freight wagon chassis, which can carry both containers and block loads such as marble, was used as the freight wagon chassis (Pugliesi et al., 2011). Two of the beams shown in Figure 2 are used in RGNS wagons. Freight wagon chassis, the skeleton is generally made of structural steel (Karagöz et al., 2020). As freight wagon material, S235 and S355 carbon steel are the most preferred materials (Shinde et al., 2017). Dimensions may vary depending on the type of wagon. There are many factors that affect freight car design (Ramos et al., 2018). These factors are the loading weight, the operating speed of the wagon, and the type of load. Some considerations need to keep in mind for the analysis of a freight wagon in Solidworks. Firstly, freight wagon dimensions for analysis are of the type of RGNS freight wagon.

Freight wagon chassis dimensions must be well-defined (Holmberg et al., 1998). Also, the factor of safety should be in limits (Baek et al., 2008).



(a) **(b)**

Figure 2. **(a)** RGNS Freight wagon chassis model. **(b)** RGNS Freight wagon chassis dimensions.

2.1. Modeling freight car chassis in Solidworks

An assembly image consisting of product parts was created with the Solidworks software. Fae analysis can be performed with Solidworks software. (Kovalev et al., 2009). The development of freight wagons and fae analysis can be done on Solidworks software. (Bojović, 2002). While creating the model, it started with a base metal drawing of 8 mm thickness and 18380 mm length. The upper and lower flanges are attached to the 22 mm thick and 200 mm wide middle plate (Table 1). The model command can be used to create a copy around the center plate. These models are also used for the FEA of the freight car chassis.

Table 1. Freight car chassis dimensions taken in Solidworks.

The length of the Freight car chassis	18380 mm.
The thickness of middle plate	8 mm.
The thickness of upper plate x width of upper plate	22 mm. x 200mm.
The thickness of bottom plate x width of bottom plate	22 m. x 200mm.

2.2. Materials properties

1023 steel is carbon steel. This steel contains a low amount of carbon in its structure. It is a very suitable material for welding. It is frequently used in building elements, especially due to its compatibility with welding. In this study, 1023 steel was preferred in terms of the preference of low carbon steels in the manufacture of railway parts. 1023 steel is often used is material of rolling stock in railway industry. Mechanical properties of 1023 steel are given in Table 2.

Table 2. Material properties.

Material	Yield Strength (MPa)	Density, (gr/cm^3)	Poisson's Ratio	Tensile strength (MPa)
1023 Carbon Steel	282	7.3	0.29	425

3. Methodology

3.1 Meshed model

In order to obtain good results, it is very important to create a high quality mesh in finite element analysis. Depending on the complexity of the structure, the networking task is often the most time-consuming task in the workflow (Kumar et al., 2021). Determining mesh size is one of the most common problems in finite element analysis (Stein et al., 2004). The smaller the items, the longer the computation time (Zhou et al., 2016). It is unlikely to know where the selected mesh size is in this row. However, by using the mesh convergence method to determine the correct mesh size in your finite element analysis, choosing the right mesh size and what mesh size analysis results are acceptable can be learned. Solidworks makes networking easy. A mesh of 3D 4 node tetrahedral elements is created. Each node has 6 DOFs. This can be accomplished by clicking the mesh icon in the simulation tree and selecting create mesh from the context menu (Escobar et al., 2011).

3.2. Topology Optimization

Target and constraint parameters determined as the best stiffness for the weight and the protected zone, the thickness control, the demoulding direction and the plane of symmetry determined in the manufacturing control parameters is so important for optimization. (Cazacu et al., 2014). Loading and structure response to it is very slow with respect to time, there exist no vibration, materials are isotropic and aerodynamic resistance is negligible (Kazakis et al., 2017). For optimization, the freight wagon simulation should be imported as 3d into Solidworks. (Sigmund, 1994). Knowing the correct value of a material property is essential for better efficiency of the analysis. The freight wagon chassis may be made up of different materials but for this study, 1023 carbon steel material was used. Using finite element analysis, it was investigated how much the freight wagon could be lightened without deteriorating its rigidity (Challis et al., 2010). Meshing method and boundary conditions are described further and boundary condition and loads are carefully applied in Solidworks. The flow chart showing the working principle of topology optimization is shown in Figure 3.

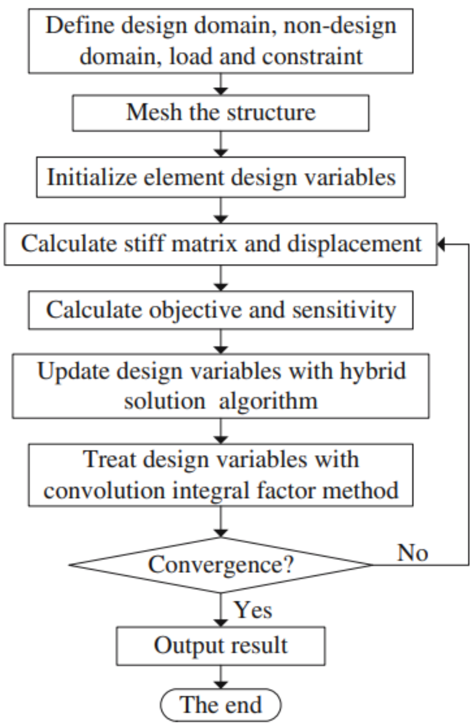
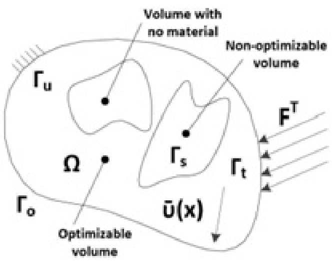
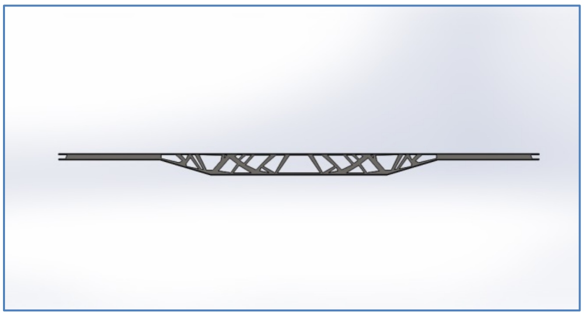


Figure 3. Flow chart of topology optimization

The main question here is how to distribute material volume into domain Ω in order to minimize a specific criterion. The usually most used criterion is the compliance C. Density values x (distributed over the domain Ω) are used to control the distribution of the material volume in the domain. It is controlled by design parameters that are represented by the densities x assigned to the finite element (FE) discretization of domain Ω is given Figure 4. The densities x take values in the range (0−1), where zero means no material in the specific point (s) (Slavov et al., 2019).



(a)



(b)

Figure 4. **(a)** Generalized shape design problem of finding the optimal material distribution in the 3D domain, and **(b)** Topology optimization part

A topology management optimization problem can be written in the general form as equations (1), (2), (3) and (4) (Kazakis et al., 2017).

$$\text{minimize x} \quad C(x) = F^T \cdot \overline{u}(x) \tag{1}$$

$$\text{subject to :} \quad \frac{V(x)}{V_0} = f \tag{2}$$

$$F = K(x) \cdot \overline{u}(x) \tag{3}$$

$$0 < x_{min} \leq x \leq 1. \tag{4}$$

4. Findings and Discussion

Run the simulation study and wait patiently for Solidworks solver to complete the analysis (Kumar et al., 2021). The desired result will be obtained on the work screen. The red area obtained shows the maximum value and dark blue is the lowest value of a parameters. The design, analysis and optimization of the chassis of the RGNS type freight wagons were carried out using Solidworks 2020. Overall dimensions remained the same. This study was carried out to reduce the weight of the chassis of the freight wagon within the safety limits. It was aimed to increase the load carrying capacity by reducing the weight of the freight wagon and to reduce the operating and manufacturing costs. As shown in Table 3. For the purposes of this study, a new design with a weight of 14.51, a volume of 14.51 and a surface area of 24.12 less than the freight wagon was created within the safety limits. The safety factor of the freight wagon, whose weight has been reduced by 14.51%, is 1.5. The fact that the safety factor is acceptable for a railway vehicle means that this design can be used in operation.

Table 3. Result of changes parameters of freight car chassis

	Freight car chassis - Standard	Freight car chassis - Optimized	Percent Change (%)
Mass (gr)	231522.19	197916.39	14.51
Volume (mm^3)	231522191.51	197916386.16	14.51
Surface area (mm^2)	33381565.81	25328515.33	24.12

4.1 Deformation and optimization results

These are the obtained deformation and optimization plots after running the study in Solidworks (Vardaan et al., 2022). It is observed in Figure 5 that maximum static stress of conventional chassis of 133.678 MPa It is observed in Figure 6 that maximum static stress of optimized chassis of 187.41 MPa. It is observed in Figure 7 that maximum static displacement of optimized chassis of 15.112 mm. It is observed in Figure 8 that maximum static displacement of conventional chassis of 13.353 mm. It is observed in Figure 9 that minimum factor of safety of optimized chassis of 1.876 It is observed in Figure 10 that minimum factor of safety of conventional chassis of 2.630.

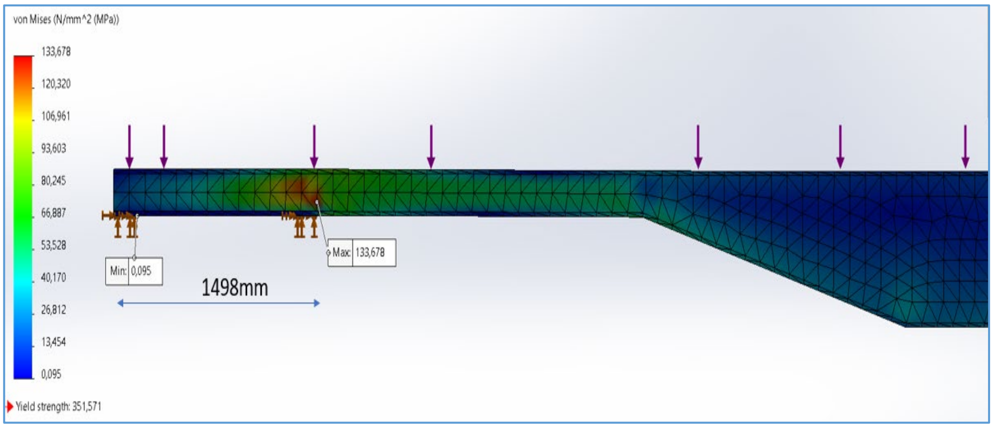


Figure 5. Static stress of conventional chassis

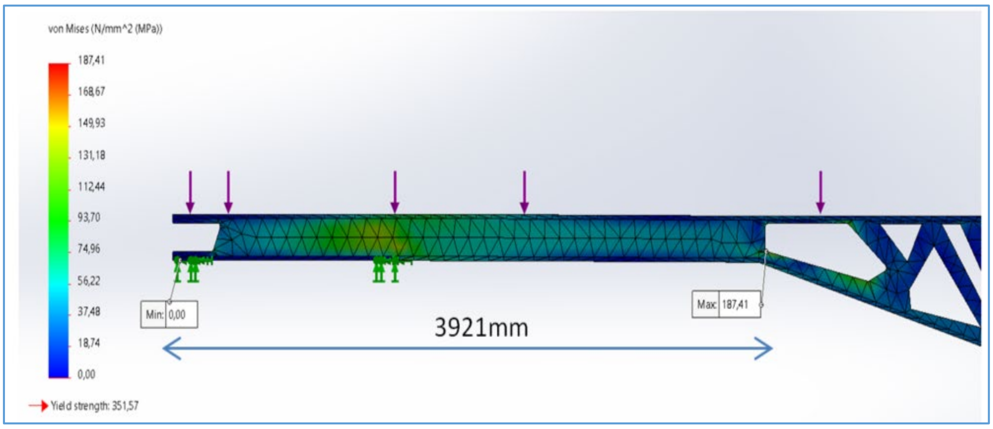


Figure 6. Static stress of optimized chassis

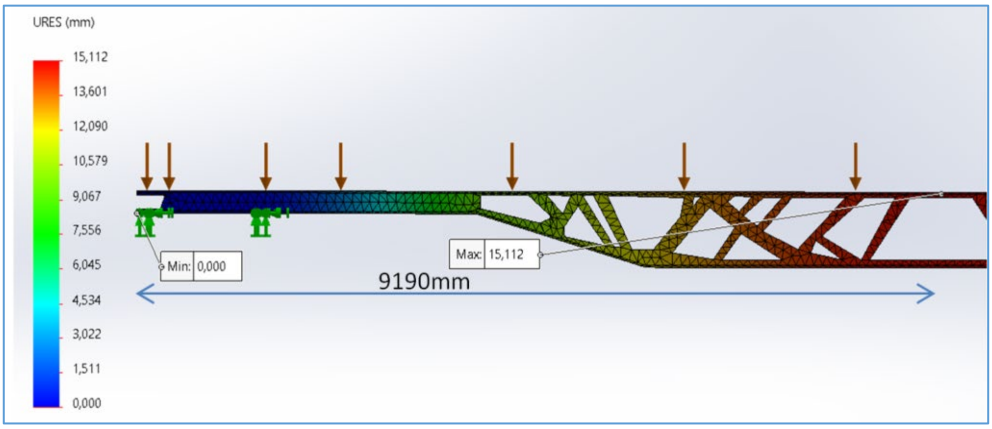


Figure 7. Static displacement of optimized chassis

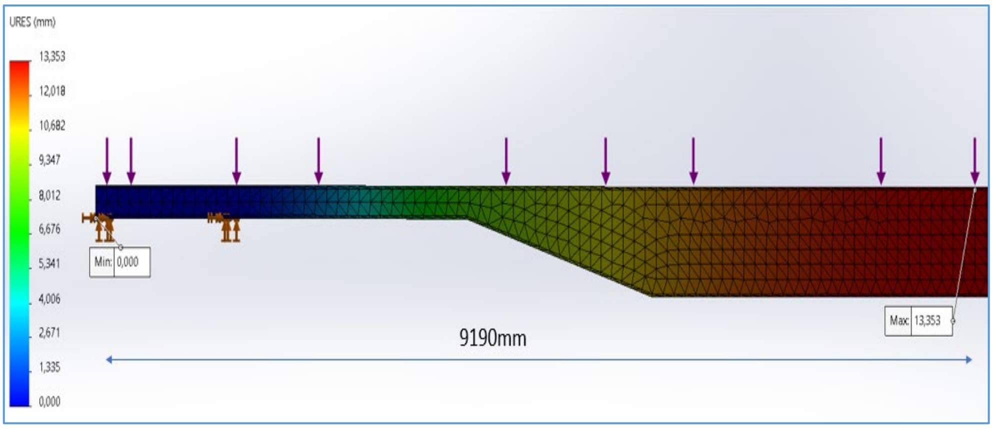


Figure 8. Static displacement of conventional chassis

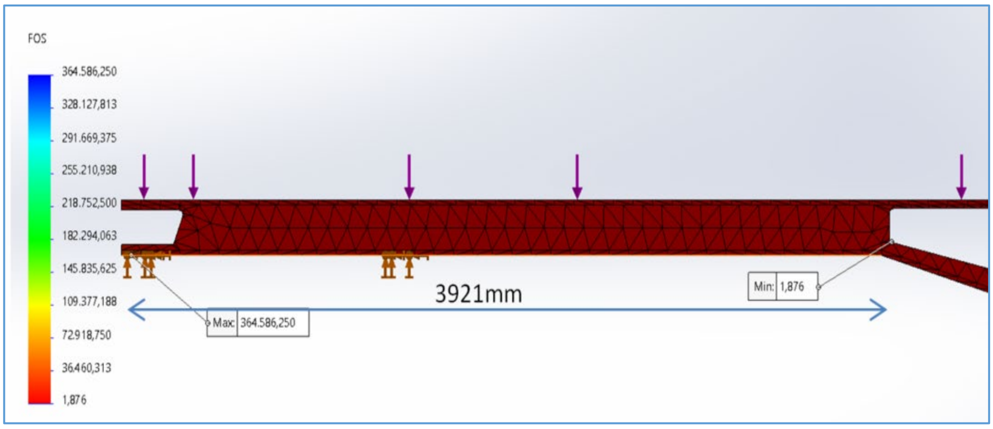


Figure 9. Factor of safety of optimized chassis

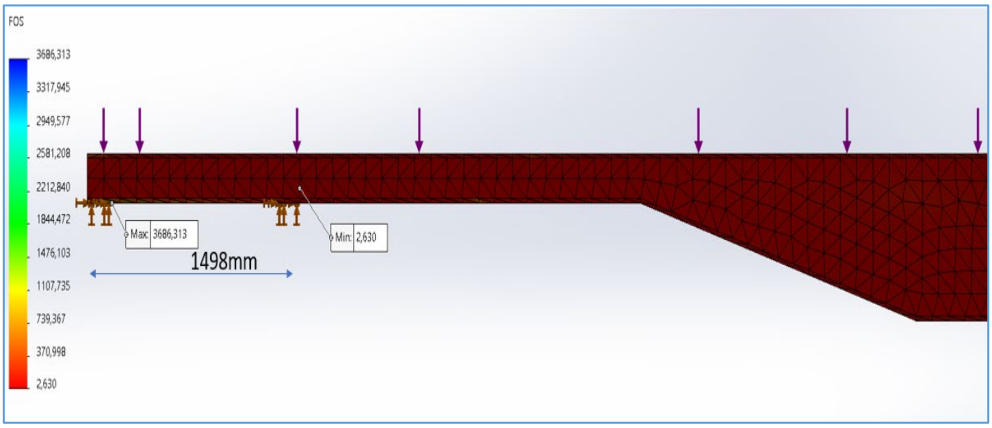


Figure 10. Factor of safety of conventional chassis

Two chassis were compared under normal loading conditions. Methods static stress, static displacement and factor of safety were chosen as comparison parameters. Despite the reduction in weight of the optimized wagon, it was found to be within the safety limits.

4.2 Deformation and optimization plots

FEA analysis results of optimized and conventional boxcar beams are compared on graphs. As shown in Figure 11 following von-mises stress plots, fos plots and typical static displacement plots (URES) plots were obtained after running the simulation study in Solidworks.

As shown in Figure 12 maximum von mises stress conventional(standard) chassis of 133.678 N/mm^2 and optimized chassis of 187.41 N/mm^2 is observed, as shown in Figure 8 maximum typical static displacement plots (URES) of conventional(standard) chassis of 15.112 mm and optimized chassis of 96.43 N/mm^2 is observed and also as shown in Figure 13 minimum factor of safety of conventional(standard) chassis of 2.630 and minimum factor of safety of optimized chassis of 1.876 is observed.

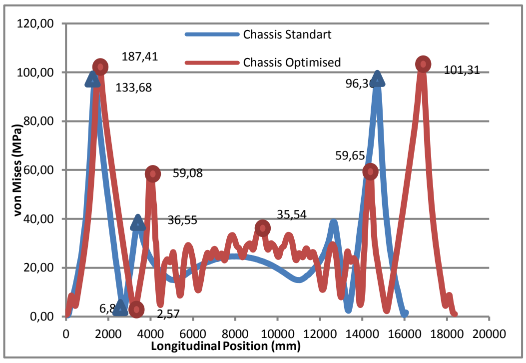


Figure 11. Von mises plot.

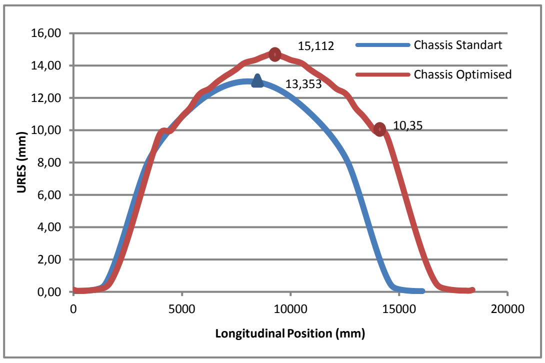


Figure 12. URES plot.

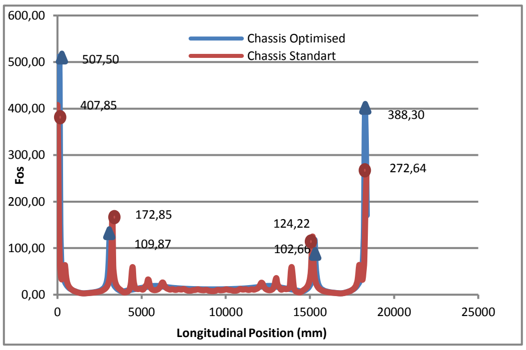


Figure 13. Fos plot.

Looking at Figure 11, the changes in the geometry of both wagons created the peak points in the von mises values. In the middle parts of the wagon, it was observed that the values in the optimized wagon chassis were more fluctuating. It was thought that the aforementioned wavy values were related to the chassis geometry formed as a result of optimization. Although the von mises values had fluctuating values in the middle of the chassis, it was observed that they were within the safety limits. For each wagon chassis, there is a stretching margin within certain limits according to the relevant standards. The deflection in question is taken into account when choosing the wagon chassis material. As can be seen in Figure 12, 1.63 mm difference was observed between the URES values of the two-wagon chassis.

5. Conclusions and Recommendations

This optimization study means that each freight wagon can carry a load of 14.51, ie 33605 g, for one beam. Considering that two beams are used in a freight wagon, this value is 67210 g. It is obvious that this study will increase with the application of other structural parts of the wagon. It is determined that it is possible to lighten a freight wagon much more within the same safety limits. Thus, it has been seen that it is possible to minimize production methods such as materials, workmanship, welding and cutting. Optimization studies on the wagon chassis are important not only in terms of manufacturing but also in terms of reducing operating costs.

Regulations made in the railway sector impose limitations on the sum of the weight of the wagon chassis and the load it carries. Optimization work on the railway chassis also means that the wagon can carry more cargo.

Authors' Contributions

All authors contributed equally to the study.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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