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Procedia CIRP 100 (2021) 37–42

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31st CIRP Design 2021 (CIRP Design 2021)

Model design and finite element analysis of a traction link of a railcar

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Abstract

The traction link is a key component of the railcar suspension system which is used to transmit force and provide acoustic and vibration isolation. To ensure satisfactory performance of the railcar suspension system, the traction link should be properly designed. In this study, the traction link is considered as a component for local manufacturing. The aim of this study is to provide a guided approach on the design and simulation of the part to ensure that it meets the service and functional requirements. To clearly understand the effect of vibration and variable alternating loading on the mechanical integrity of the railcar suspension system, the designed traction link was analysed using finite element analysis. . Dynamic analysis on the traction link was done using a linear perturbation analysis tool in the commercial FEM software ABAQUS©. The results show that the component is designed to a safe limit for the required service condition and that the material chosen is unlikely to deform under extreme conditions of the system. It is envisaged that the findings of this study will assist manufacturers in the development of railcar suspensions system that will meet the required service conditions.

Keywords: FEA, railcar, stress, traction link, vibrational effect

1. Introduction

The traction link is a component of the railcar bogie system used for force transmission and for providing acoustic and vibration isolation. The traction link auxiliary system is specifically designed to transfer traction and braking force between the railcar and the body in order to reduce dynamic vibration. The proper design and optimization of the traction link are very necessary steps in ensuring satisfactory performance of the component is service. The rods of the traction link system are usually designed to transfer high force while providing consistent mobility at the same time. Many countries are already embarking on the concept of component localization in an attempt to revamp their railway sector [1]. In the context of the rail sector, the concept of localization is a policy aimed at the development of certain railcar components through the deployment of indigenous technology and capabilities. Instead of relying extensively on the importation of certain railcar components, the technology, skills and capabilities required for such components can be developed locally. The advantages of localisation include: cost effectiveness (reduction in the cost of the component and the overall assembly), reduction in the manufacturing lead time (reduction in the time in between the ordering and delivery of such component), opening of new business and employment opportunities, development of human capacities, technology transfer, reduction in the system's downtime due to a quick fix in any case of breakdown, increase in the Gross Domestic Product (GDP) and economic stability amongst others [2-3]. However, the early stage of localisation and component development may adhere to the principle of the Bathtub curve where failure rate may be high but rapidly decreasing due to the identification and disposal of defective components until it stabilizes at the mid-life marked with low and constant rate of failure. This is due to the fact that at the initial stage of component localisation, some factors such as inadequate knowledge and technology transfer, design flaws, lack of standardization in terms of processes and procedures may contribute to the development of poor quality products when compared to the global standards [4]. Hence, in a bid to localise components that will meet the service and functional requirements, the design process must be taken into consideration. An inadequately designed traction link system will cause an increase in vibration and reduction in the mobility of the railcar system. Consequent upon this, the energy requirement of such system will increase with tendency of noise generation, ride discomfort, and failure of the suspension system. This implies that it could breed safety and operational concern with

10.1016/j.procir.2021.05.006

cost implications. Several authors have reported on the use of the FEA, modelling and simulation tools to determine the behavior of railcar components under different loadings. For, instance Zhang [5] reported on the FEA of railway track under vehicle dynamic impact and longitudinal loads. The results of the FE simulation predicted the behaviour of the selected materials and were found to be in significant agreement with the experimental results. Singh [6] compared the performance of carbon steel and composite as materials for the side wall of a light rail vehicle using the FEA approach in the ABAQUS environment. The study showed that the FEA modelling and simulation tool used were able to determine the behaviour of different materials under the same loading conditions. This agrees significantly with the results of some existing studies [7-12]. Nejad [13] employed the 3-D FEA for the modelling and simulation of residual stresses in railway wheels. The results obtained indicate significant agreement between the numerical and experimental values, thus, validating the FE model. Furthermore Kukulski *et al.* [14] investigated the strength properties of a railway surface and its elements using the FEA approach in the ABAQUS environment. The results obtained indicate the suitability of the FEA tool to simulate a technological or production process of the railway turnout elements. There has not been much work reported on the design of the traction, including the model design and finite element analysis. Hence, this work provides a guided approach in the application of finite element modelling and simulation using the Abaqus software to investigate the load transmission capacity of the traction system under ideal and extreme conditions. It is envisaged that the findings of this study will assist railcar manufacturers in the development of a traction link system that will meet the required service conditions. The succeeding sections of this paper present the materials and method, results and discussion, conclusion and direction for future study.

2. Materials and Method

In order to effectively compare the significance of the component redesign proposed in this study, there is a need to present the existing state of design and the proposed design from the original design, material, and production methods point of view.

The flowchart for the methodology employed in this study is presented in Figure 1.

As mentioned earlier, the traction link, was analysed using a Finite Element Analysis (FEM) tool. This was necessary to gain understanding on the effects of variable alternating loadings on the mechanical integrity of the railcar structures and components. Dynamic analysis was conducted using a linear perturbation analysis tool in the commercial FEM software ABAQUS©. This is to investigate the load carrying and transfer capacity of the traction link. A properly designed traction link will provide adequate support for the weight of a railcar and reduce dynamic vibration between the railcar and bogie assembly by absorbing and transferring traction and breaking force, while also connecting other components to the assembly. The understanding of the dynamic response of the designed component and other components of the railcar suspension system is thus an important venture, especially during the design phase. This is due to the fact that potential defects can easily be identified and rectified at this stage before proceeding to the advanced stage of fabrication.

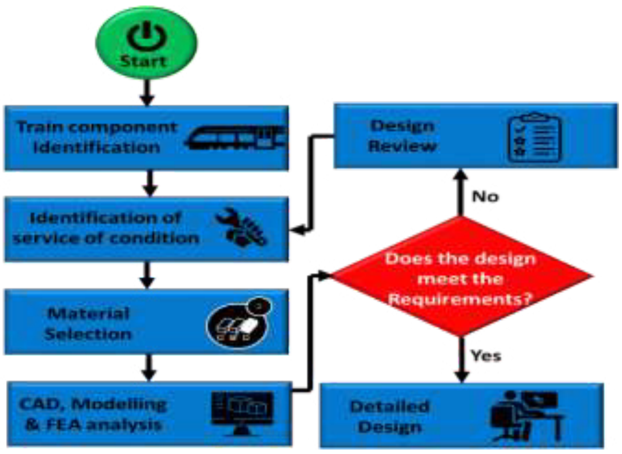

Fig. 1. The flowchart for the methodology.

2.1 Existing and proposed design

The traction and braking force transmission to the rail car body can be achieved in two ways: through pivot point (pivot assembly) or through the traction link (rod). The pivot assembly boasts of low manufacturing cost but the system is rigid and susceptible to horizontal bend of the pivot beam. In order to achieve significant reduction in the overall weight of the system, this work proposes the direct connection of the railcar body to the bogie through the use of the traction link (as shown in Figure 2).

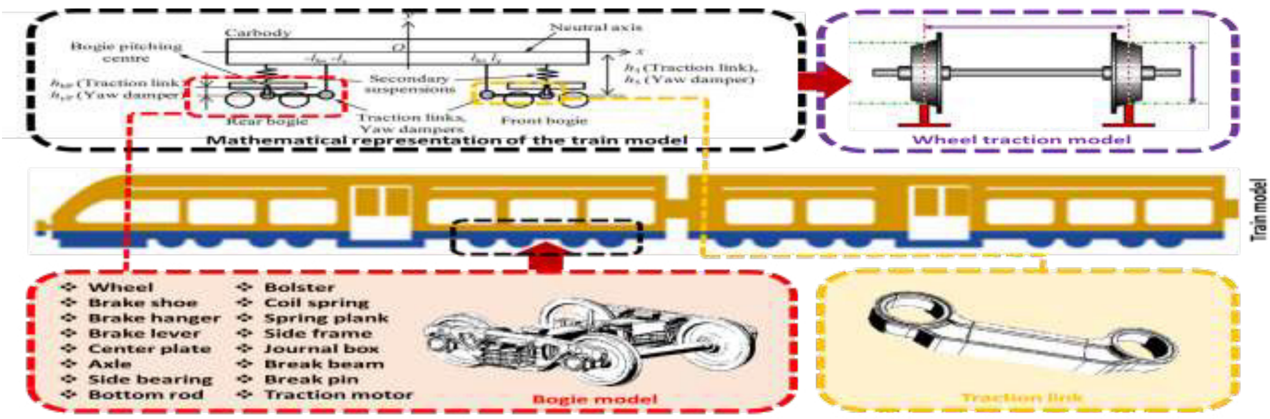

Fig. 2. The model of the traction link.

In order to damp the oscillation resulting from traction and braking force, the traction link will be equipped with flexible but tough rubbers. By this design, some metallic parts in the pivot assembly has been replaced with rubbers thus bringing about significant weight reduction. The new design is optimized to enhance transmission of high force while providing efficient mobility with improved resistance to abrasion. According to this proposed design, the rubber component will meet the stiffness requirement. The link is also designed such with flexible couplings between the axle motor and gearbox. This will make the motor mass to be supported on the truck frame while the gear box and the couplings assembly are supported on the axle. In many conventional design, the loads from the weight of traction and braking force are placed upon the main frame thereby resulting in increased weight, reduction in speed and high energy consumption. The rubber bushes in the traction rod ends to which the traction link is attached will provide effective resistance to yaw thereby making the system more stable.

2.2 Existing and proposed material

Existing materials usually employed for the pivot assembly or traction link have been steel material of various grades. This study considers the stainless steel ASTM A36 and the choice of the material was informed by its excellent mechanical properties such as the high tensile strength and corrosion resistance.

2.3 Existing and proposed production method

Mostly the pivot assembly are welded having tendencies for the development of residual stresses, overlapping welds and flexural deformation which can bring about horizontal bends in some part of the beam. For the traction link developed conventionally, the component is usually fabricated via the casting process. The casting process is liable to defects such as porosity, shrinkage and dimensional inaccuracies. The process of casting involves significant investment to cater for the equipment and tooling costs unlike the AM process. In this study, Additive manufacturing (AM) is proposed for manufacturing the traction link. AM is a group of technologies in which parts or assemblies are produced directly from computer aided design (CAD) models through selective deposition of materials [15]. The reasons for selecting AM is that it does not require initial tooling investment and it provides design freedom [16-18]. With AM, parts that are difficult to produce with conventional processes can be easily manufactured without the need for addition effort. Wire Arc Additive Manufacturing (WAAM) is selected as the most suitable AM process for producing the part because it is more economic when compared to other metallic AM processes that use powder [19]. Considering the fast build rates (up to 4.5 kg/hr) and affordable raw materials (metal wire) which are easier to handle, WAAM can replace many conventional processes [20]. Powder bed fusion processes (PBF) can produce highly complex parts, however, they have limited build volumes, the cost of powder is high and the deposition rates are generally low [21]. The WAAM process has a wide range of material applications and can produce medium complex parts with mechanical properties which meet industrial standards [22]. The proposed process chain for producing the part with WAAM is shown in Figure 3.

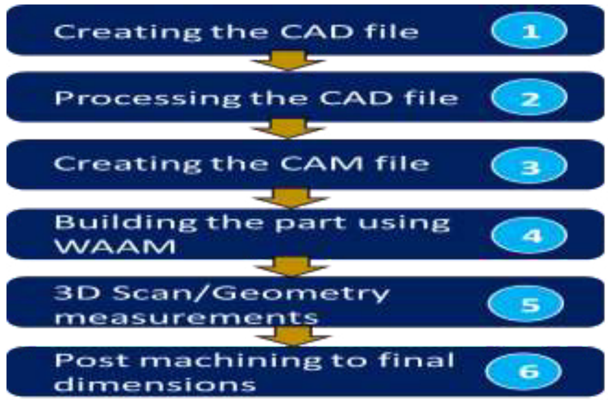

Fig. 3. The proposed process flow chain.

The simulation tool can enhance the understanding of certain phenomenon and with reduction in the number of expensive as well as time-consuming trial runs, thus, making the process cost and time effective [23]. The intricate shape of the traction link requires non-linear analysis for thorough investigation of the dynamic multi-faceted problems inherent in component under the required loading condition. Hence the software which incorporates the non-linear parameter-dependent aspects associated with modelling with the FEA will be suitable for the required operation [24-27].

The choice of ABAQUS from an array of different FEA and modelling tools stems from the fact that the software can simulate the performance of a material under different loading conditions (static and dynamic) and has significant applications with both pre-processing and post-processing capabilities [5, 28]. Also, the software allows for visualization of the results with a robust users' interface for a wide range of industrial and engineering applications. In addition, the software can be used for conducting basic or advanced linear and non-linear analysis including stress and vibration analysis and structural acoustics amongst others [5, 28].

The choice of high strength steel (ASTM A36) was informed by its excellent mechanical properties such as the high tensile strength and corrosion resistance [29]. The extensive library of material models provided by ABAQUS was used to simulate the potential behaviour of some shortlisted engineering materials and the steel material demonstrated superior performance compared to others under the same loading conditions.

The part was drafted on the complete Abaqus environment, as shown in Fig. 4, using standard traction link dimensions as a solid homogenous part of ASTM (A36) steel material.

A steady-state dynamic linear perturbation analysis step with a unit step period was created, with default parameters and a 5% damping coefficient. Encastre boundary conditions were imposed on the shank of the traction link to restrict its degree of freedom in all directions while the damper grooves where bounded in all directions bar the translational x and y coordinates. The vibration loading and amplitude parameters were defined in the load module with characteristic PSD amplitude definition, dictating the frequency dependence of the random loading for a random response analysis.

As shown in Fig. 4, a combination of 8-node 3-D continuum linear brick hexagonal elements with reduced integration (for the shank) and 10-node general purpose quadratic tetrahedron elements with improved surface stress visualization elements (for the grooves) were used to mesh the elements to enhance computational convergence and accuracy. In order to ensure a balance between computation cost and efficiency, mesh convergence study was carried out which yielded an element size of 0.044 mm as one which will guarantee a balance of accuracy in results and computational convergence. The modelled traction link can potentially undergo plastic deformation. Accordingly, the nonlinear analysis enabled by the ABAQUS software allows for effective stress-strain and displacement analysis of the traction link

The von Mises stress analysis was employed as the failure criterion. The magnitude of the resulting stresses induced due to loading were compared with the yield strength of the material to give an indication of the performance of the component under different loading conditions.

Tables 1 and 2 presents the mechanical properties of the material selected for the development of the traction link and the design specifications for the traction link system.

Table 1. Materials properties ASTM (A36) steel [29]

Property	Value
Density ($\boldsymbol{\rho}$)	7850 kg/m^3
Poisson's ratio ($\boldsymbol{\mu}$)	0.29
Young modulus ($\boldsymbol{E}$)	211 MPa
Shear modulus ($\boldsymbol{G}$)	82 GPa
Tensile strength ($\boldsymbol{P}$)	730 MPa
Yield strength ($\boldsymbol{k}$)	556 MPa
Elongation ($\boldsymbol{\delta}$)	25%

Table 2. Design specifications for the traction link system.

Parameter	Value
Rod head (diameter) $\boldsymbol{d}$	160 mm
Length of link ($\boldsymbol{l}$)	1200 mm
Operating load range	20-350 kN
Maximum load ($\boldsymbol{P}$)	340 kN
Radial stiffness ($\boldsymbol{k}$)	150 N/mm
Weight ($\boldsymbol{w}$)	40 kg

According to Khurmi and Gupta [30], the mathematical expression for the Von Mises stress analysis employed as the criterion for the failure analysis in the traction link is expressed by Equation 1.

$$(\sigma t_1)^2 + (\sigma t_2)^2 - 2\sigma t_1 \times \sigma t_2 = (\frac{\sigma y_t}{F.S})^2 \quad (1)$$

Where: σt_1 is the maximum principal stress (N/mm^2) ,
σt_2 is the minimum principal stress (N/mm^2)
σy_t is the stress at yield point (N/mm^2) ,
$F.S.$ is the factor of safety

The stress induced in the traction link is expressed by Equation 2 while the area of the rectangular and the hollow sections are expressed by Equations 3 and 4 respectively.

$$\sigma = \frac{F}{A} \quad (2)$$

Where: F is the force applied (N); and
A is the cross sectional area of the link (mm^2)

$$A = \frac{\pi D^2}{4} \quad (3)$$

$$A = \frac{\pi(D_o^2 - d_1^2)}{4} \quad (4)$$

Where: D is the diameter of the rectangular link (mm), D_0 is the external diameter (mm) and d_i is the internal diameter of the hollow part of the traction link. From the design calculatiions, length of the link

3. Results and Discussion

The stress, deformation and strain results of the analysis are shown in Fig. 5-7. As shown in Fig. 4. Instantaneous stress levels in the component due to instantaneous vibrations can rise from 0.8361 kPa to 31.97 MPa, at the grooves which directly absorb energy and forces from other components attached to it or to the linkage. The stress induced in the material ranges from a minimum value of 836.1 Pa to 31.97 MPa as presented in Fig. 5. Comparing these values with the yield strength of the material 556 MPa, it shows the material is unlikely to yield to permanent deformation under the normal loading conditions. Although it is obvious that the induced stress increases most especially at the area near the grooves. This can be traced to the fact that the magnitude of load absorption and transfer at the grooves exceeds other parts of the linkage. This thus makes the region more susceptible to deformation as shown in Fig. 6. Fig. 6 is a superimposed deformed and undeformed visualization of the component, showing how it is likely to deform during vibration with reference to its initial fixed point. The deformation ranges from a minimum value of 2.948×10^{-7} mm to a maximum value of 6.613×10^{-5}. Although the deformation is relatively small, there is an indication of the propensity of the areas near the grove to deform plastically. The elastic and plastic strain distributions are represented in Fig. 7 and 8 respectively. According to the figures, plasticity is not likely going to be induced by instantaneous vibration, but continual or prolonged elastic straining caused by variable body accelerations and vibrations. These accelerations and vibrations may contribute to other failure mechanisms such as creep or buckling of the component. From Fig. 7, both the minimum and maximum values of the strain were 0. This shows that the capacity of the material to return to its initial state and dimensions after load transfer. Further loading beyond this point, gave a plastic strain which ranges from a minimum value of 5.40×10^{-12} and maximum value of 1.313×10^{-4} respectively. This implies that the material can develop plastic strain over time under a continuous loading condition. However, since both the yield strength and tensile strength of the material are not exceeded under the service condition, it can be deduced that the design will meet the required service condition. The results further implies that the resulting vibration due to the applied load can easily be isolated without causing any significant ride discomfort. Fig. 9 shows that there exist a direct relationship between the stress induced in the traction link and the corresponding elongation. The elongation measures the magnitude of the deformation in the material before rupture. This implies that as the stress induced increases, the corresponding deformation also increases and vice versa. Fig. 10 shows the relationship between the stress induced and the elastic as well as plastic strain developed due to the stress. The figure shows that the relationship between the stress induced and the elastic strain developed is directly proportional. This implies that an increase in the magnitude of the stress induced results in an increase in the elastic strain developed and vice versa. The relationship between the stress induced and the plastic strain could not be established due to the fact that within the range of the stress induced no plastic strain was developed.

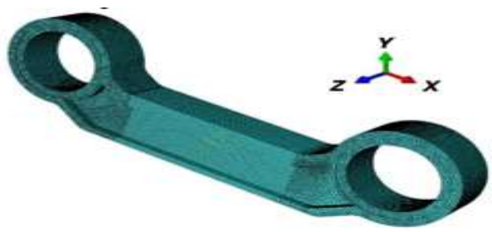

Fig. 4. Meshed model of the traction link.

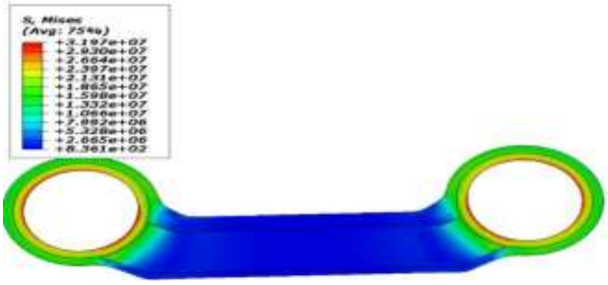

Fig. 5. The stress distribution.

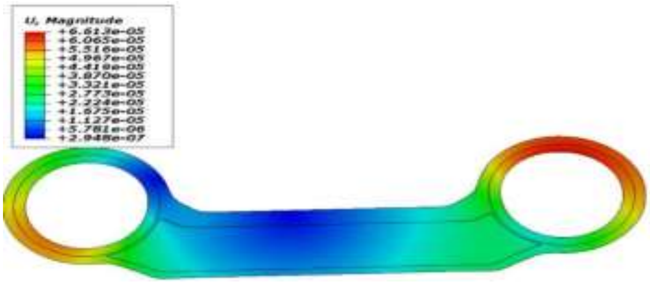

Fig 6. The deformation distribution due to loading.

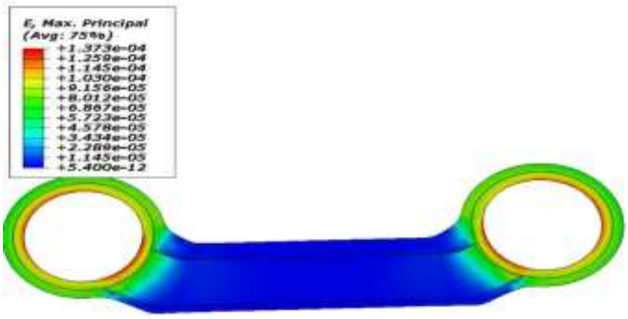

Fig. 7. The elastic strain distribution

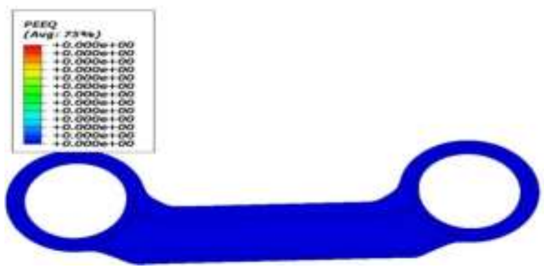

Fig. 8. The plastic strain distribution.

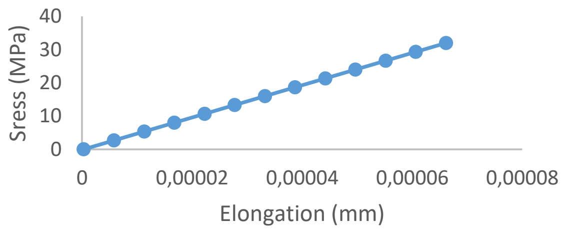

Fig. 9. The stress-elongation distribution.

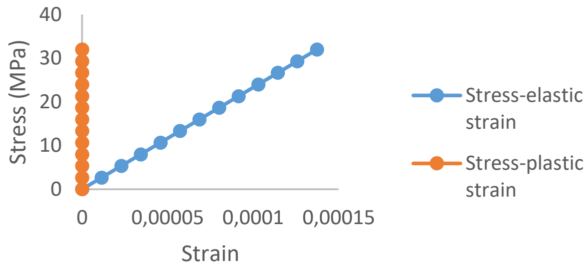

Fig. 10. The stress-elastic and plastic strain distribution.

Existing works on the bogie and railcar suspension systems have linked the failure of the bogie, suspension system and its components under varying loading conditions to fatigue, stress and uncontrolled vibrations [31-41]. This work have been able to demonstrate that the design of the traction link to safe stress limits under the required loading conditions. Hence, these challenges can be solved with the development and implementation of the component redesign. The process of the redesign and FEA results obtained show that the redesign is highly promising with evidence of adequate strength against failure, weight reduction and effective load transmission ability coupled with sustainability in terms of material and energy conservation.

4. Conclusion

The aim of this study was to model the design and FEA of the traction system for a railcar for development via the additive manufacturing process. The purpose of the analysis was to provide an insight into the load transmission capacity of the traction system. Using the linear perturbation analysis tool in the commercial FEM software ABAQUS© for the dynamic analysis, the results obtained showed presence of instantaneous stress levels in the component due to instantaneous vibrations.

The magnitude of the stress induced increases especially at the grooves which directly absorb energy and forces from other components attached to it. This thus makes the region susceptible to deformation during vibration with reference to its initial fixed point. However, the results further indicate that the component is designed to a safe limit for the required service condition as shown by the magnitude of the induced stresses due to load transmission which were found to be less than the yield and tensile strength of the material. The results obtained also show that the material is unlikely to deform elastically, this is explained by the slight propensity for plastic deformation. The relationships between the stress induced and the elongation as well as the elastic strain developed were found to be directly proportional. The redesign of the traction link shows tendency for improved load transmission capacity, weight reduction and sustainability in terms of materials and energy consumption as well as environmental friendliness at the preliminary design stage. It is envisaged that the findings of this study will assist manufacturers in the development of railcar suspensions system that will meet the required service conditions. Future works can consider the detailed design of the traction link and the experimental validation of the numerical results obtained.

Acknowledgements

Funding: The authors disclosed receipt of the following financial support for the research: Technology Innovation Agency (TIA) South Africa, Gibela Rail Transport Consortium (GRTC), National Research Foundation (NRF grant 123575) and the Tshwane University of Technology (TUT)."

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This is a resupply of March 2023 as the template used in the publication of the original article contained errors. The content of the article has remained unaffected.