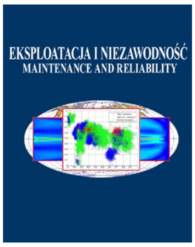

Eksploatacja i Niezawodnosc – Maintenance and Reliability

Volume 24 (2022), Issue 1

journal homepage: http://www.ein.org.pl

Article citation info:
Mysior M, Pietrucha G, Koziołek S. Strength testing of a modular trailer with a sandwich platform. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2022; 24 (1): 163–169, http://doi.org/10.17531/ein.2022.1.18.

Indexed by: Web of Science Group

Strength testing of a modular trailer with a sandwich platform

Marek Mysior[a,*], Grzegorz Pietrucha[b,*], Sebastian Koziołek[a]

[a]Wroclaw University of Science and Technology, Faculty of Mechanical Engineering, Department of Machine and Vehicle Design and Research, ul. Łukasiewicza 7/9, 50-371 Wroclaw, Poland
[b]HONEYtech Sp. z o.o., Huta 58, 98-360 Lututów

Highlights

- The work describes the experimental testing process of light trailers.
- The test was conducted on trailers equipped with a sandwich panel and a plywood.
- Performed bench test made it possible to evaluate operational parameters of trailers.
- The described method represents experimental testing on a special testing track.
- A trailer equipped with a sandwich panel has higher stiffness and durability.

Abstract

The article presents the experimental strength evaluation of modular car trailers with a maximum permissible total mass of up to 3500 kg and its application to assess the mechanical strength of box-type car trailers. Tests were carried out using an original test bench dedicated to fatigue testing. They aimed to compare a trailer made in traditional technology with a trailer equipped with a load-carrying structure containing a sandwich panel. As a result of the conducted work, the displacement values of the measurement points were measured. The deformation form of the trailer made in the traditional technology was compared with the trailer containing the sandwich panel. The proposed method of experimental strength evaluation of modular car trailers enables a quantitative assessment of the mechanical strength of the load-carrying structures of trailers. This results in improved safety of trailer operation in road traffic by identifying the critical elements of the load-carrying structure at the early design phase before the trailer is allowed to run on the road.

Keywords

fatigue life, light trailer, road testing, sandwich panel, honeycomb.

1. Introduction

The issue of reliability and durability of machines, devices, and vehicles is widely discussed worldwide. An essential element of the conducted research in the field is concerned with predicting and modeling the durability of mechanical objects [3, 4] and assessing their service life [10]. Mathematical and statistical methods are of particular interest in determining useful features of a mechanical object [12]. Apart from this, the growing diversity of useful functions of products leads to the increased variety of design features of designed mechanical objects. This represents an increasing number of design variants that should be durable and reliable. As a consequence, there is an urgent need to develop a novel design and testing methods dedicated to ordered design families.

In conceptual and detailed design, product modularity is currently getting more attention. It is defined as the ability to create functional variants out of a set of modules, which form a future technical object [18]. In modular products, implementation of design changes requires lower usage of time, information, material, energy, and space resources than integral products, and the later the change is implemented, the more resources it requires [17]. As vehicles are concerned, high implementation costs also result from obtaining an official certification, which is costly and time-consuming. It means that all the issues in design identified during vehicle exploitation may require a complete redesign, which significantly increases the total investment cost to implement a product on the market.

The issues mentioned above make it necessary to look for novel methods to evaluate the mechanical strength and durability of machines and vehicles that can be implemented at an early design stage, when the cost to implement a change is the lowest. For those changes to be effective, knowledge of quantitative criteria describing useful functions of a designed system is necessary. Durability, defined as a time in which an object keeps operational parameters valuable to users, is regarded as one of them. It directly impacts both safety and usefulness of a product.

Current vehicle testing is connected mainly with active and passive safety assessment [19] and mechanical strength evaluation for static and fatigue loads. Criteria used for this evaluation can result from formal standards [6, 13] or researchers' experience. A widely used method for mechanical strength evaluation is the Finite Elements Method. It is commonly used to assess the durability of vehicle frames [1, 5] and load transferring parts [2] in static [1], fatigue [25], impact [16], and mixed loading [20]. The advantage of numerical testing is the

(*) Corresponding author.

E-mail addresses: M. Mysior (ORCID: 0000-0002-9973-704X): marek.mysior@pwr.edu.pl, G. Pietrucha (ORCID: 0000-0002-6635-4069): grzegorz.pietrucha@innovento.pl, S. Koziołek (ORCID: 0000-0002-5440-8146): sebastian.koziolek@pwr.edu.pl

possibility to assess mechanical strength without needing a physical prototype, which reduces design costs [15]. On the other hand, numerous simplifications and uncertainty of relevance of applied boundary conditions is a drawback of this method. Because of that, experimental testing methods are still used that can be divided into bench testing and empirical evaluation on a test track. Both types aim to evaluate strength and durability of individual components as well as entire vehicles. In this paper, authors concentrate on experimental strength evaluation of light trailers.

Experimental testing conducted on dedicated testing tracks is used to assess durability in operational conditions, although it is not formally required by the certifying authority [9, 14]. During testing, a vehicle is subjected to a specified load cycle that simulates extreme operational conditions in road exploitation. This cycle comprises passage through several types of pavements that induce loads on the structure of a vehicle. The quantitative characteristic of a testing cycle is determined by the type of vehicle and its planned exploitation. It is established that the total distance covered by a vehicle on a testing track represents an operational distance increased by the factor of 10. This means that a distance of 400 km traveled on a test track represents 4 000 km in road exploitation [14]. Experimental testing on special tracks reduces the amount of time needed to assess the safety of a vehicle in the scope of cyclic loads. However, this type of evaluation is time-consuming and costly due to the necessity of transporting uncertified vehicles to a test track to perform long-lasting trials.

An alternative form of experimental testing is connected with bench testing, in which individual vehicle components [7] or assemblies [21] are being evaluated on dedicated test platforms. Parts usually subjected to this type of testing are mechanical coupling devices, load-carrying frames, drawbars, and others [23]. Research apparatus typically consists of a test platform, actuators, fixing systems, and data acquiring units. Often, the analysis outcome is the identification of cracks and deflection measurement [22].

The above-described bench testing methods of vehicle strength, including light trailers, consider the limited variety of the load cycles; thus some of the load cycles existing in operational conditions are skipped. Moreover, such tests require specialized data acquiring units that make it possible to evaluate the fatigue life of the analyzed object.

In this paper, the authors present a novel method of experimental strength evaluation of trailers, equivalent to a full-scale assessment on a special test track. The work done consisted of empirical testing of two types of a light trailer on a special testing track and comparing the obtained results with the outcome of the bench testing of the same trailer types. The application of test loads and their duration were adjusted to represent the conditions existing during testing on a track. As a result, both trailer types were compared from an operational point of view.

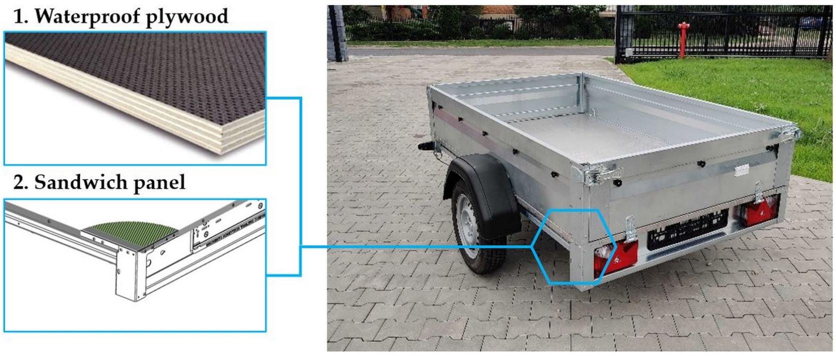

Fig. 1. Picture of the examined trailer

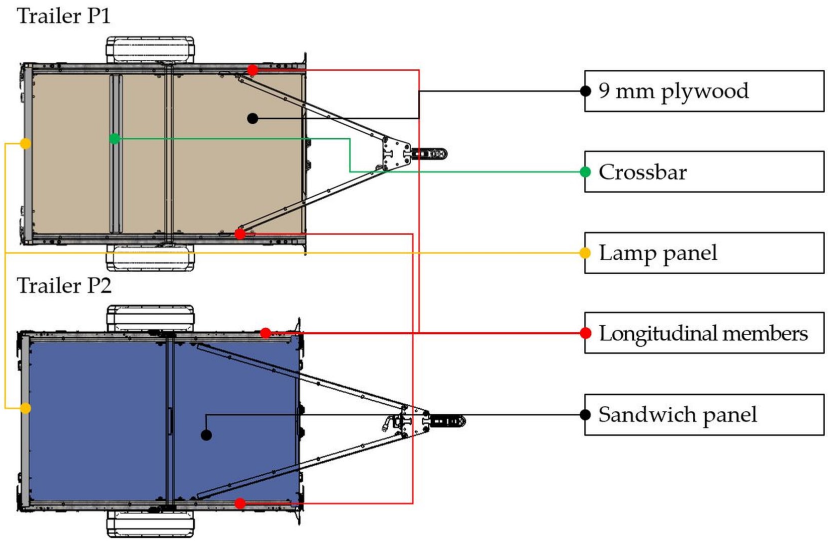

Fig. 2. Comparison of load carrying structures of the type 1 (top) and type 2 (bottom)

2. Research method and object

In this paper, two types of light trailers were examined that differed in the manufacturing technology. Each trailer was characterized by a TPLM (Total Permissible Laden Mass) of 750 kg, corresponding to vehicle category O1. Both types were equipped with a single unbraked axle and V-shaped drawbar having a B50-X coupling head. Dimensions of the loading box were 129 cm x 204 cm. Fig. 1 presents a photograph of one of the examined trailers with a floor description.

First examined trailer (P1) was characterized by a floor made of a 9 mm thick waterproof, antislip plywood attached to the frame comprising two steel longitudinal members and one crossbar. The second trailer (P2) was manufactured using HONEYtech technology, characterized by a honeycomb plate used to strengthen the load-carrying structure. Like the first type, the floor plate was supported by two longitudinal members but without any crossbar. The comparison of load-carrying structures of both trailer types is shown in Fig. 2.

A scheme of the applied experimental strength evaluation method of trailers is shown in Fig. 3.

The presented method involves a bench test of trailers with a TPLM of 750 kg. It consists of four steps. In the first step, a trailer is assessed to verify its dimensional conformity to the trailer types tested on a test track. Those dimensions are related to the loading box, coupling point, and axle positioning. Next, a trailer is prepared for a bench test by attaching a loading frame to the lashing eyes of the trailer using transport belts. The remaining mass is supplemented with an evenly distributed loose material. The bench test is conducted continuously, with an excitation frequency of 22 to 26 Hz.

Every trailer subjected to testing is analyzed based on loading box diagonals and floor deformation measurements. The result of the bench test is considered positive if both diagonals are within their tolerance range and floor deformation is not bigger than 5%. The method presented in Fig. 3 was applied to assess the strength of both trailer types and is described in detail in chapter 4. The upcoming chapter describes validation studies of trailers on a test track.

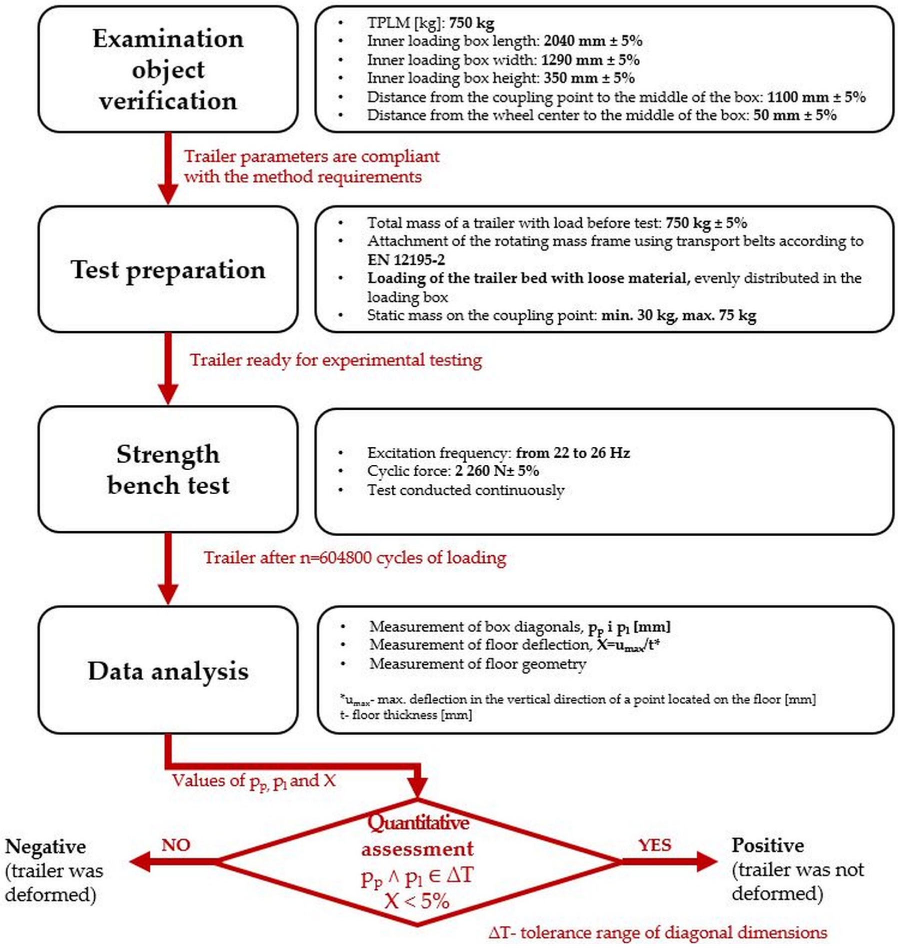

Fig 3. Diagram showing an original method of experimental strength bench test

3. Experimental evaluation of trailers on a testing track

Both trailer types (P1 and P2) were examined on a test track with the same loading cycle, traveling through resonance, rocky, and winding trails with a total distance of 20 km. Fig. 4 shows a picture of a test track with each of the used trails. Parametric description of test trails is shown in Table 1.

Evaluation of a plywood trailer (P1) on a test track resulted in a permanent change in the geometry of the loading box. This phenomenon was not observed for the trailer equipped with a sandwich panel (P2). Comparison of geometric forms of both trailers after testing on the track is shown in Fig. 5. Both trailers survived 100% of the test.

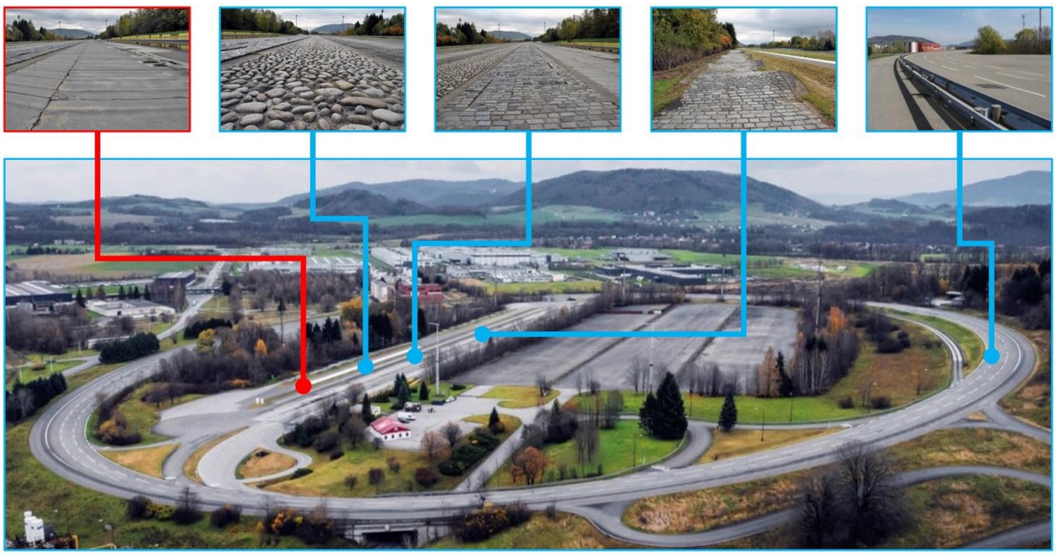

Fig 4. Picture of the TATRA Testing Grounds showing test trails used in experiment. Kopřivnice, CZ [24]

Table 1. Parametric description of test trails

	**Length**: 400 m **Obstacle height**: 0,02 m, **Obstacle spacing**: 0,770 m. **Max. velocity**: 60 km/h Made of concrete plates. Used for generation of cyclic dynamic loads for functional testing of vibrating elements and durability of vehicles.
	**Length**: 400 m **Dist. between rocks**: from 0,1 to 0,3 m. **Placement density**: od 20 do 30 pcs/m^2. **Effective height of obstacles**: 0,015 m. **Max. velocity**: 60 km/h Pavement made of 15-30 centimeters high granite stones, embedded from ½ to ¾ in flat concrete.

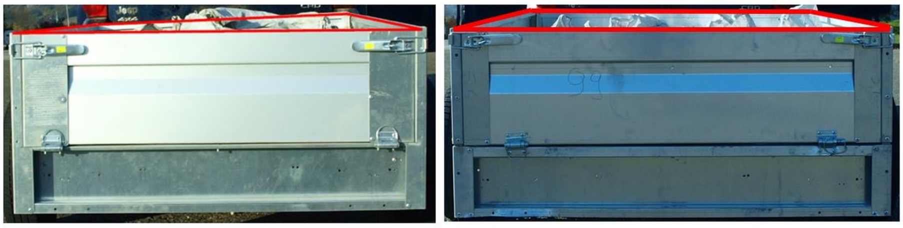

Fig. 5. Deformation form of evaluated trailers. A plywood trailer (P1) on the left and a trailer equipped with a sandwich panel (P2) on the right

4. Bench testing of trailers

After experimental evaluation of both trailer types on a test track, authors focused on creating a bench testing method that resembles the conditions met on the track. To meet this assumption, the proposed method had to fulfill a set of requirements that were defined in the literature [9]:

1. A method should make it possible to evaluate a complete trailer in the same configuration as during testing on a test track, **completeness condition,**
2. A method should lead to a similar deformation form as during testing on a test track, **analogy condition** and
3. A degree of that deformation should resemble the one observed during experimental evaluation on a test track, **proportionality condition**.

For this method to be effective, it is vital to determine how loads are imposed on the trailer. During testing on track, forces result from an evenly distributed load attached to the trailer structure by transport belts, which secure it to 4 corners of the box. On a test bench, a trailer is repeatedly loaded in the vertical and horizontal directions, simulating forces coming from various test trails acting on a trailer. The testing setup consisted of a coupling ball connected with a coupling head during an examination, wherein two trailer wheels supported the remaining load. A mass mount non-axially on a rotating shaft created a cyclic force acting on a trailer. Additionally, a loose material was distributed in the loading box to provide the static load. A scheme showing how forces act on a trailer during bench testing is shown in Fig. 6.

A cargo during bench testing was secured to the trailer frame by transport belts in the same way as during testing on track. Total reaction force on wheels and a coupling point corresponded to the weight of a TPLM of a trailer, i.e., 750 kg ± 5%. A cyclic load was obtained with an electric motor switched on, as shown in Fig. 7. The value of the cyclic force was selected such that the load amplitude was equal to 40% of the weight of the trailer load, i.e., 2 260 N. A change of variable force vector within a single loading cycle is shown in Fig. 8.

For a rotating mass-selected, the required value of the cyclic force was achieved with the excitation frequency of 24 Hz. This corresponds to the excitement frequency when traveling on a resonance trail with a velocity of 67 km/h. Table 2 summarizes parameters used for bench testing.

Test duration was selected based on the fulfillment of completeness, analogy, and proportionality conditions. Based on the experimental testing of trailers on a test track, the total number of cycles used in bench testing was determined to be equal to 604 800 cycles.

After bench testing of a plywood trailer, a change in the geometry of a loading box was observed. Measured values of box diagonals have shown a significant difference between right (p_p=2492 mm) and left (p_l=2509) mm diagonal, which exceeded the tolerance range for the reference dimension p=2499 ± 2 mm according to the ISO 2768-1 standard. From the operational point of view, visible damage to the trailer floor resulted from an influence of sand and a vibrating frame on the floor. This led to the formation of visible scratch marks and fissures, impacting the waterproof properties of the plywood.

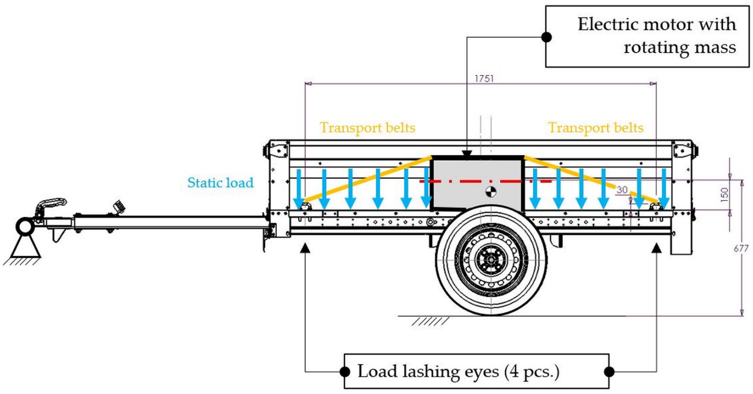

Fig 6. A loading scheme of a trailer on a test bench

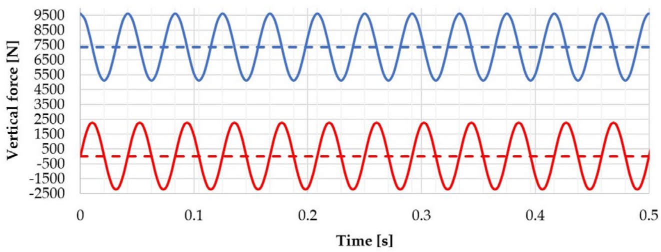

Fig. 7. The course of a cyclic load during bench testing

Analyzing the second type of trailer (P2), there was no visible deformation of a loading box, as observed with the first trailer type (Fig. 9). Additionally, the trailer kept all operational abilities of sideboards,

Table 2. Quantitative parameters describing bench testing of trailers

	Horizontal load	Vertical load
$\mathbf{F_A}$ [N] (*amplitude*)	2260	2260
$\mathbf{F_M}$ [N] (*mean value*)	7358	0
$\mathbf{F_{max}}$ [N] (*max. value*)	9618	2260
$\mathbf{F_{min}}$ [N] (*min. value*)	5098	-2260
f [Hz] (*excitation frequency*)	24	

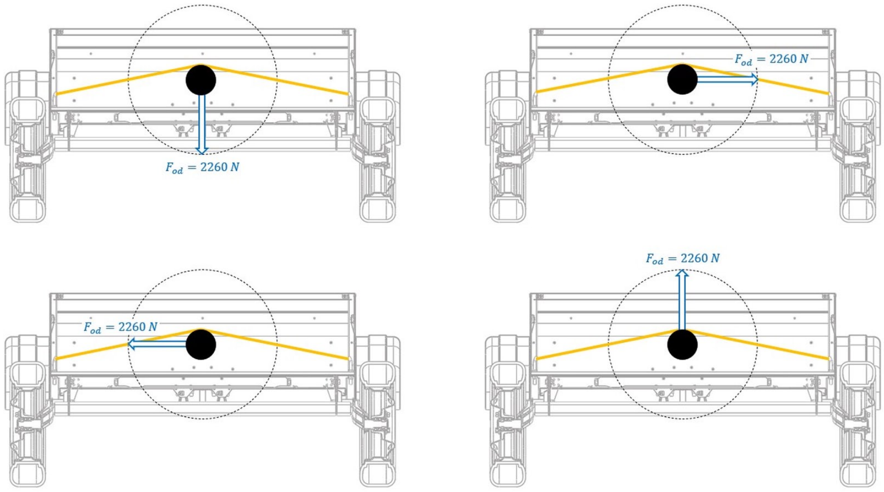

Fig. 8. Change of a loading force within a cycle

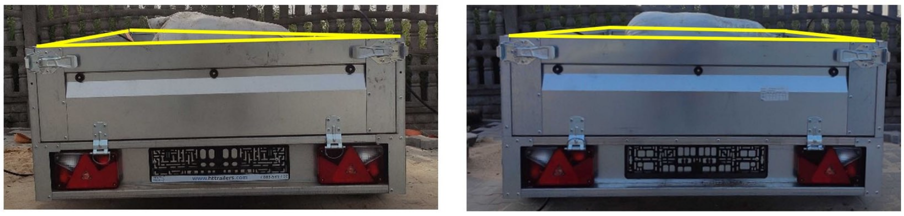

Fig. 9. Comparison of geometric forms of a plywood trailer (on the left) and a trailer equipped with a sandwich panel (on the right)

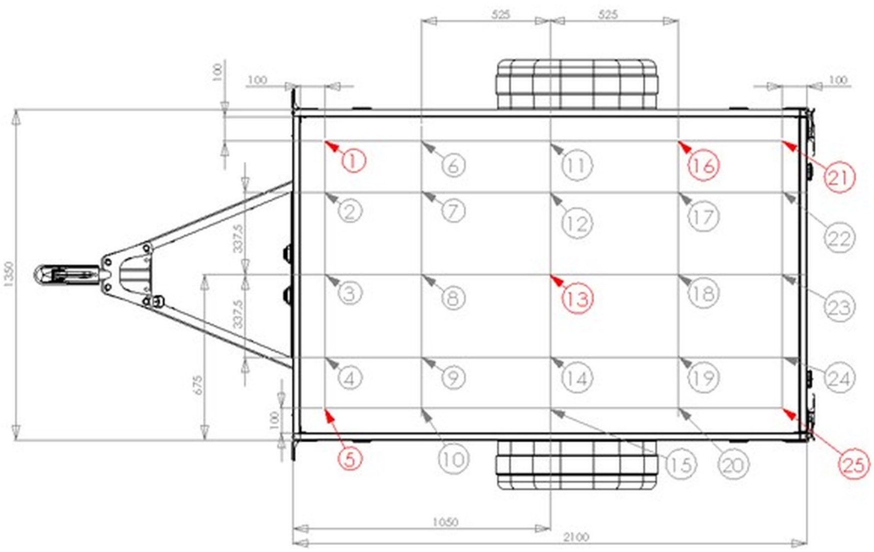

Fig. 10. Measurement points located on a trailer floor

locks, and hinges, together with the proper operation of a tilt feature. Measured values of box diagonals showed no difference between left (p_l=2498 mm) and right diagonal (p_p=2498 mm), remaining in the tolerance range for the reference dimension p=2499 ± 2 mm according to the ISO 2768-1 standard.

To confirm that the trailer type P2 was not deformed during bench testing, additional measurements were conducted for a given set of measurement points located on the top of the trailer floor, as shown in Fig. 10.

Measurements were made vertically with respect to a leveled base using an analog sensor. During measurements, a trailer was supported on longitudinal members of the frame, eliminating the influence of the suspension and tires deflection on the measurement results. Fig. 11. shows measured values of the vertical position of measurement points before (blue) and after bench testing (green), with respect to the same measurement base.

Measured differences between vertical position of measurement points before and after bench testing for P2 type trailer is shown in Fig. 12. The maximum difference was equal to 1.91 mm. Only four points (13, 14, 18, 19) had a difference of more than 1 mm.

5. Discussion and conclusions

An original method of experimental strength evaluation of trailers was used to examine two types of trailers having different load-carrying structures. The dimensions of their loading box and method of load lashing for both trailers were the same. Results obtained from experimental testing of trailers on a track were compared with those from bench testing. In Fig. 13, a comparison between deformations for both trailer types are shown for bench and track testing.

The track and bench testing results in similar deformation forms and degrees for two kinds of trailers. This concludes that analogy and proportionality conditions were met during bench tests for both analyzed trailer types, i.e., deformation forms for a corresponding trailer type match for two examination methods. Since complete trailers were analyzed in both track and bench tests, the condition of completeness is also satisfied, and the proposed bench testing method represents experimental testing on a track. It means that the loading cycle comprises traveling through resonance, rocky, and winding trails with a total distance of 20 km is equivalent to 604 800 cycles of loading on a test bench.

Based on the results of experimental testing of a modular trailer having a load-carrying structure equipped with a sandwich panel (type P2), neither permanent deformation was observed nor any damages, scratches, or breaks that could negatively impact the operational features of the said trailer. The difference in both diagonal lengths of the loading box was smaller than 1%. In the other trailer (type P1), a visible deformation of a loading box was observed, impacting the vehicle's operational values, including aesthetics and appearance of a trailer. Furthermore, the deformed shape of the trailer box has a negative impact on the positioning of accessories, i.e., the cover stand attached to four corner posts. If a trailer is deformed, the assembly process of the said stand will be more complex and will require additional force.

Also, after the assembly, residual stresses will exist in the structure of the cover stand. Observed deformation form and extent is a typical

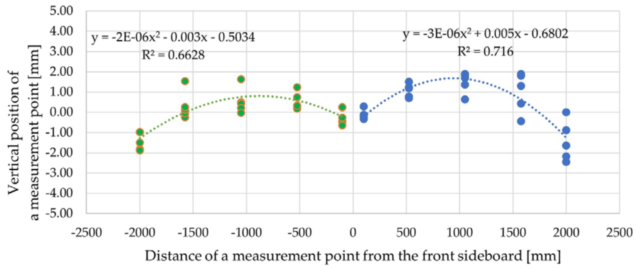

Fig. 11. Measured values of the vertical position of measurement points before (blue) and after bench testing (green)

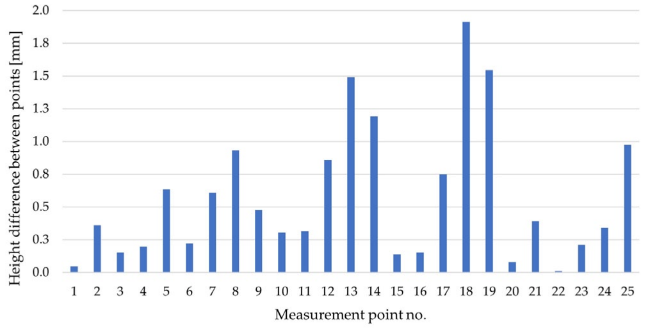

Fig. 12. Measured differences between vertical position of measurement points before and after bench testing for P2 type trailer.

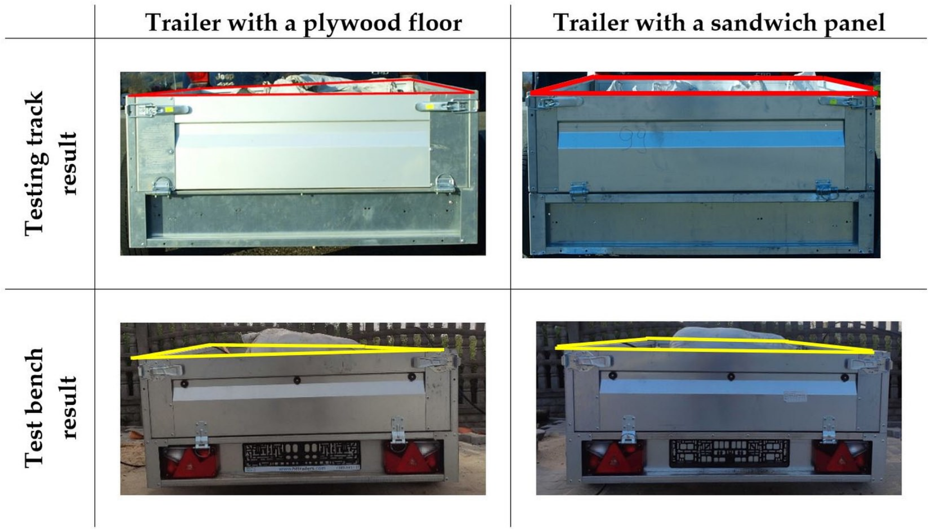

Fig. 13. Comparison of track and bench testing results of both trailer types

phenomenon in exploiting trailers currently available on the market. Recently, a standard thickness of a plywood floor was equal to 12 mm. Nowadays, in pursuit of manufacturing cost reduction, producers tend to reduce the price of a trailer by substituting it with thinner plywood. This leads to reduced stiffness of the trailer and, as a result, to its deformation in operation.

The lack of loading box deformation of trailer P2 makes it possible to conclude that the stiffness of the load-carrying structure of said trailer increases compared to already existing solutions because of an application of a sandwich panel. This finding confirms current research in the field [8, 11]. This stiffness is vital for trailer behavior on the road, influencing motion stability and certainty of driving. From the operational point of view, sandwich panels make it possible to use metallic materials on the top of the floor, including stainless steel. This is a desired feature in exploitation, connected with increased corrosion resistance and ease of cleaning. Furthermore, as compared to regular plywood, no damage in the form of scratches or fissures was observed for this type of floor panel. Also, due to the increased stiffness of the sandwich panel, there is no need to use additional strengthening elements, i.e., crossbars, which simplifies the trailer's assembly process.

The presented method of experimental strength evaluation of trailers is an original and effective way to determine the durability of trailers with a TPLM of 750 kg and can be used to assess the operational values of designed vehicles. It represents the expensive and time-consuming track testing meaning, that for trailers having defined dimensions and TPLM, it is possible to limit a research agenda to bench testing. If a change in TPLM or trailer sizes occurs, it is necessary to validate the proposed method for a broader range of initial parameters. It is connected with a different loading cycle on a test track, depending on the designed trailer having other operational parameters. The proposed method of bench testing makes it possible to examine a full-scale prototype without special preparation of the test specimen. It proves the versatility of the proposed method, unlike already existing solutions in bench testing. Furthermore, the approach fits broad research agendas, including but not limited to quality control of the full-scale prototypes of a trailer and verification of conformity with official requirements. This represents an evolutionary approach in vehicle design that increases the design process's effectiveness by identifying those areas that should be improved before vehicle certification and exploitation in road traffic.

The article presents results of a project: "Modular, multifunctional and ultralight trailer manuafactured in a flexible production system" project no.: POIR.01.01.01-00-0563/17 and „Flexible production system (ESPP) of modular car trailers with GW up to 3500kg manufactured in HoneyTech technology", project no.: POIR.01.01.01-00-0589/19, realized within Measure 1.1 „R&D projects of enterprises", Sub-measure 1.1.1 „Industrial research and development work implemented by enterprises", Project co-financed by the European Union from the European Regional Development Fund under the Smart Growth Operational Programme 2014-2020. Data used for analysis and conducted research together with its results are the sole property of above project beneficiaries.

References

1. Caban J, Nieoczym A, Gardyński L. Strength analysis of a container semi-truck frame. Engineering Failure Analysis 2021; 127(February): 105487, https://doi.org/10.1016/j.engfailanal.2021.105487.
2. Chudzik A, Warda B. Fatigue life prediction of a radial cylindrical roller bearing subjected to a combined load using FEM. Eksploatacja i Niezawodnosc - Maintenance and Reliability 2020; 22(2): 212-220, https://doi.org/10.17531/ein.2020.2.4.
3. Chybowska D, Chybowski L, Guze S, Wilczyński P. A method for determining critical events during large disasters of production platforms. Journal of Loss Prevention in the Process Industries 2021; 72: 104528, https://doi.org/10.1016/j.jlp.2021.104528.
4. Chybowska D, Guze S. A Multiphase Process Approach to the Analysis of the Reliability and Safety in Maritime Transport Systems.

TransNav, the International Journal on Marine Navigation and Safety of Sea Transportation 2020; 14(4): 985-990, https://doi.org/10.12716/1001.14.04.25.
5. Dębski H, Koszałka G, Ferdynus M. Wykorzystanie mes w analizie struktury nośnej ramy naczepy o zmiennych parametrach eksploatacyjnych. Eksploatacja i Niezawodnosc - Maintenance and Reliability 2012; 14(2): 107-114.
6. Działak P, Karliński J. Comparative examination of the trailer frame in accordance with UIC 596-5. Materials Today: Proceedings 2019; 12: 416-422, https://doi.org/10.1016/j.matpr.2019.03.144.
7. Kozłowski E, Borucka A, Szymczak E, et al. Predicting the Fatigue Life of a Ball Joint. Transport and Telecommunication Journal 2021; 22(4): 453-460. https://doi.org/10.2478/ttj-2021-0035
8. Giglio M, Gilioli A, Manes A. Numerical investigation of a three point bending test on sandwich panels with aluminum skins and NomexTM honeycomb core. Computational Materials Science 2012; 56: 69-78, https://doi.org/10.1016/j.commatsci.2012.01.007.
9. Halfpenny A. Methods for accelerating dynamic durability tests. 9th International Conference on Recent Advances in Structural Dynamics 2006: 1-19.
10. Han Y, Lin Y, Zhang C, Wang D F. Customer-related durability test of semi-trailer engine based on failure mode. Engineering Failure Analysis 2021; 120(September 2020): 105095, https://doi.org/10.1016/j.engfailanal.2020.105095.
11. He M, Hu W. A study on composite honeycomb sandwich panel structure. Materials & Design 2008; 29(3): 709-713, https://doi.org/10.1016/j.matdes.2007.03.003.
12. Kamiński Z, Kulikowski K. Determination of the functional and service characteristics of the pneumatic system of an agricultural tractor with mechanical brakes using simulation methods. Eksploatacja i Niezawodnosc - Maintenance and Reliability 2015; 17(3): 355-364, https://doi.org/10.17531/ein.2015.3.5.
13. Karlinski J, Ptak M, Chybowski L. A Numerical Analysis of the Working Machine Tyre Inflation Process to Ensure Operator Safety. Energies 2019, https://doi.org/10.3390/en12152971.
14. Kepka M, Kepka M, Václavík J, Chvojan J. Fatigue life of a bus structure in normal operation and in accelerated testing on special tracks. Procedia Structural Integrity 2019; 17: 44-50, https://doi.org/10.1016/j.prostr.2019.08.007.
15. Koziołek S. Inżynieria Wynalazczości. Metodologia projektowania innowacyjnych systemów technicznych. Wrocław, Oficyna Wydawnicza Politechniki Wrocławskiej: 2019.
16. Mackiewicz A, Pyka D, Pach J et al. Comparison of Numerical Modelling Methods of Innovative Materials for Ballistic Shields. 2020: 119-127, https://doi.org/10.1007/978-3-030-34123-7_13.
17. Mysior M, Hnat W, Koziołek S. Method of Identification of Useful Functions in the Scope of Technical System Development. 2019, https://doi.org/10.1007/978-3-030-32497-1_17.
18. Mysior M. Metoda projektowania maszyn oraz urządzeń w aspekcie modułowości. 2021.
19. Ptak M. Method to Assess and Enhance Vulnerable Road User Safety during Impact Loading. Applied Sciences 2019; 9(5): 1000, https://doi.org/10.3390/app9051000.
20. Rusiński E. Zasady projektowania konstrukcji nośnych pojazdów samochodowych. Wrocław, Oficyna Wydawnicza Politechniki Wrocławskiej: 2002.
21. Szymczak T, Brodecki A, Kowalewski Z L, Makowska K. Tow truck frame made of high strength steel under cyclic loading. Materials Today: Proceedings 2019; 12: 207-212, https://doi.org/10.1016/j.matpr.2019.03.115.
22. Szymczak T, Brodecki A, Sobolewski T. Laboratoryjna ocena stanu technicznego komponentów do pojazdów samochodowych. Przegląd Techniczny 2021.
23. Szymczak T, Cholewiński S, Sobolewski T. Badania wytrzymałościowe i stanowiskowe - jako narzędzie do oceny jakości technicznej materiałów i komponentów konstrukcyjnych związanych z bezpieczeństwem ruchu drogowego. Bezpieczeństwo Ruchu Drogowego 2020; 3-4: 21-24.
24. Tello L, Castejon L, Malon H et al. Development of a fatigue life prediction methodology for welded steel semi-trailer components based on a new criterion. Engineering Failure Analysis 2020; 108(January 2019): 104268, https://doi.org/10.1016/j.engfailanal.2019.104268.