Scientific Journal of Silesian University of Technology. Series Transport
Zeszyty Naukowe Politechniki Śląskiej. Seria Transport

Volume 124 **2024**

p-ISSN: 0209-3324

e-ISSN: 2450-1549

DOI: https://doi.org/10.20858/sjsutst.2024.124.4

Journal homepage: http://sjsutst.polsl.pl

Article citation information:
Caban, J., Nieoczym, A., Matijošius, J., Kilikevičius, A., Drozd, K. Analysis of the construction of the car trailer frame in terms of changing the assembly technology. *Scientific Journal of Silesian University of Technology. Series Transport*. 2024, **124**, 47-61. ISSN: 0209-3324. DOI: https://doi.org/10.20858/sjsutst.2024.124.4.

Jacek CABAN[1], Aleksander NIEOCZYM[2], Jonas MATIJOŠIUS[3], Artūras KILIKEVIČIUS[4], Kazimierz DROZD[5]

ANALYSIS OF THE CONSTRUCTION OF THE CAR TRAILER FRAME IN TERMS OF CHANGING THE ASSEMBLY TECHNOLOGY

Summary. Car trailers are quite a popular means of transport and are offered in many versions, from single axle light trailers with a maximum permissible weight of 750 kg, through two- or more-axle specialized trailers. The issues of research car trailers focus on two directions: testing the driving properties and analysing the strength of the supporting frame system. Issues related to the construction of light trailers are often common to trailers used in agriculture or general transport. In this article, based on a mass-produced car trailer, an analysis was carried out regarding the choice in the technology of making the supporting structure consisting of a lower frame and an upper frame. The term upper frame should be understood as the structure on which the lifted load box rests. The costs of materials, assembly and

---

[1] Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland. Email: j.caban@pollub.pl. ORCID: https://orcid.org/ 0000-0002-7546-8703
[2] Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland. Email: a.nieoczym@pollub.pl. ORCID: https://orcid.org/0000-0002-9725-8483
[3] Institute of Mechanical Science, Faculty of Mechanics, Vilnius Gediminas Technical University, Plytinės g. 25, LT-10105 Vilnius, Lithuania. Email: jonas.matijosius@vilniustech.lt. ORCID: https://orcid.org/0000-0001-6006-9470
[4] Institute of Mechanical Science, Faculty of Mechanics, Vilnius Gediminas Technical University, Plytinės g. 25, LT-10105 Vilnius, Lithuania. Email: arturas.kilikevicius@vilniustech.lt. ORCID: https://orcid.org/0000-0002-4039-7300
[5] Faculty of Mechanical Engineering, Lublin University of Technology, Nadbystrzycka 36, 20-618 Lublin, Poland. Email: k.drozd@pollub.pl. ORCID: https://orcid.org/0000-0002-6605-1172

technological possibilities of small-scale production were taken into account. In addition, strength analyses of the numerical models were carried out for critical areas of the frame during operation. After considering the unit costs for each of the analysed assembly technologies, it was shown that riveting would be the cheapest. However, the most suitable method of assembly is welding, as it allows the use of standard profiles.

Keywords: road vehicles, montage, joining, strength analysis, production costs

1. INTRODUCTION

Road transport is the most popular type of transport for moving people and goods. It provides great freedom of movement, and the multitude of means of wheeled transport makes it quite universal. An additional advantage is the possibility of connecting the vehicle with a trailer, which increases the usability in the field of transporting various goods. Car trailers are quite a popular means of transport and are offered in many versions, from the simplest single-axle light trailers with a gross vehicle weight of 750 kg, through two- or more-axle specialized trailers. As noted by Ladra and Posiadała [13], however, many car trailer solutions are dedicated to specialized transport, which limits the construction of trailers to specific types of transport, i.e. very often they are only single-purpose trailers.

In the publications on car trailers, two topics dominate: the study of driving properties and the analysis of the strength of the supporting frame system.

The study of the system: vehicle-trailer in terms of dynamics is performed due to the requirements related to driving safety [11, 17, 25, 26]. In the work [28], it was found that axle load transfer and braking force distribution have a large impact on the dynamic stability of the combine: a vehicle with a single axle trailer. The stability of the vehicle and the vehicle with a trailer was also analysed in the following works [2, 12, 22]. The published results are frequently used in general issues of vehicle motion concerning the behaviour of the vehicle when driving on unevenness and on a curvilinear track. For example, articles [1, 29] present the results of dynamic tests of a single-axle trailer when driving through a simulated obstacle. It was shown that the system did not reach the highest acceleration values (the most important for safety of the cargo) when the wheel hit the obstacle, but only when the trailer later bounced off the road. Another aspect of road safety is the effects of a collision with a vehicle towing a trailer [19] and the stability of the load carried on the trailer loading platform [5]. Noteworthy are publications [23, 27] where the authors included simulations of load displacements under the influence of dynamic impact caused by a road collision.

The second issue is related to the strength analysis of designed trailers or activities aimed at modifying existing structures. The published research results are mainly related to the designs of specialized trailers that are not included in the sales offer [10]. Another example is the design of a multipurpose light trailer [14], which combines structural solutions used in trailers for transporting small loads, motorcycles, quads, or kayaks.

Issues related to the construction of light trailers are often common to trailers used in agriculture or general transport. An example is the strength analysis of the frame of a single-axle tractor trailer [4]. There are maps of stresses and displacements of the frame with the indication of detailed load cases affecting the strength. The methodology for optimizing the dimensions of the beams forming the trailer frame is contained in publication [16]. The authors presented the results of their work based on the frame of a specialist trailer designed to transport rolls of straw. Aimed at minimizing the weight of the frame while meeting the strength limitations, it was carried out in two procedures: changes in the thickness of the profile walls and the use of steel profiles and a different shape of the cross-section. Due to the stability of the transported load on the trailer, an important issue is to determine the centre of gravity [18, 20, 24]. The variables here were: the type of trailer and the weight and dimensions of the load.

Most of the large trailers and semi-trailers are made of steel sheets and cold bent metallurgical steel profiles, made in the technology of welding and riveting. Smaller car trailers are made of standard steel profiles, and sometimes composite materials are used. The frames of these trailers are made in the technology of welding, riveting or by means of threaded connections.

In this article, based on a small-scale produced car trailer, an analysis was carried out regarding the change in the technology of making the supporting structure consisting of a lower frame and an upper frame. The term upper frame should be understood as the structure on which the lifted load box rests.

2. METHODOLOGY

The main purpose of the work was to indicate whether it is possible to change the production technology of the load-carrying system of a self-dumping car trailer. For this purpose, solid models of trailer frames were made in three different technologies: riveting, bolting and welding, as well as a strength analysis was carried out using the finite element method (FEM).

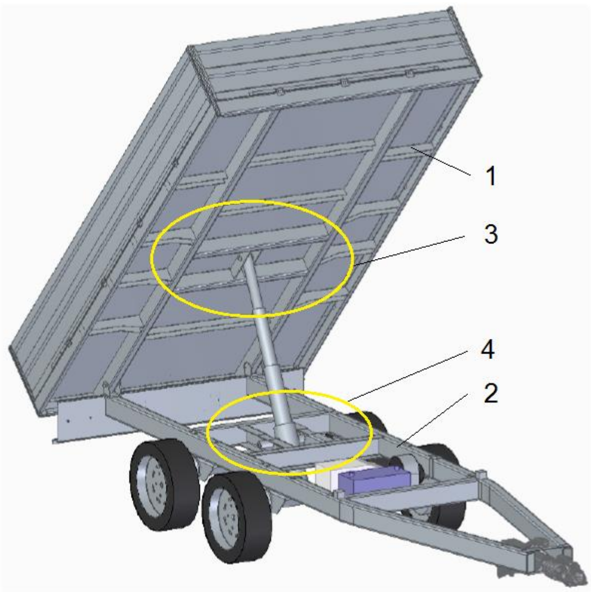


Fig. 1. Axonometric view of the trailer in the maximum lift position: 1 – upper frame, 2 – lower frame, 3 – actuator mounting node in the upper frame, 4 – actuator mounting node in the lower frame

The modified trailer is a two-axle self-dumping trailer equipped with a hydraulic cylinder. The permissible total weight of the trailer is m = 2000 kg. The strength analysis using FEM was carried out for the initial moment of the unloading process, i.e. when the cylinder piston rod advances and the upper frame is raised. Then, the sup-port points of the load box frame are changed, and the load is transferred to the nodes (Fig. 1, items 3, 4) in which the cylinder is mounted. The load on these elements' changes with the change of the angle of the upper frame, and the maximum value is recorded for the angle value in the range of 1.0°-1.5° [4, 15].

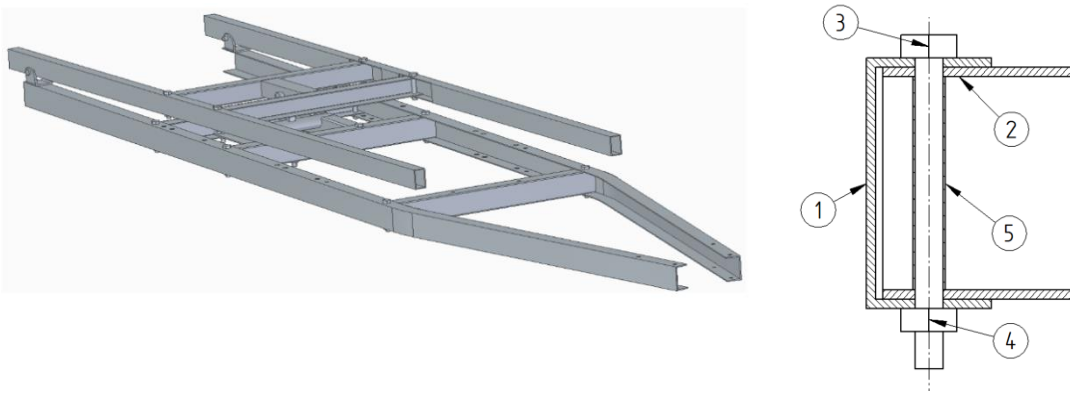
In each of the three cases of design, it was assumed that the frame elements are made of S335JR structural steel with a yield strength of *Re* = 355 MPa. During the FEM strength analysis, a 3 mm hex sweep mesh was applied to all elements. The number of finite elements was equal to 358,557. The load to which the frame models were subjected reflected the case of a uniformly distributed load in the volume of the load box. The maximum force in a hydraulic cylinder resulting from the permissible load weight is equal to *F* = 17,000 N.

The next step was to prepare technical documentation containing lists of beams of the upper and lower frames, indicating whether they are standard profiles or made of sheets of steel. The last stage of the study was to analyse the costs of making trailer frames for the three indicated manufacturing technologies.

3. RESULTS AND DISCUSSION

3.1. The construction of frames made in the technology of twisting

The load bearing structure of the original trailer frame (Fig. 2) is made in the connection technology with the use of M8 bolts and nuts. The sleeve with an outer diameter of 14 mm and a wall thickness of 1.8 mm is used to increase the rigidity of the structure (Fig. 3). Thanks to the sleeves, the connected channels are not deformed when tightening the fasteners.



(a) (b)

Fig. 2. Trailer frame assembled using threaded connections: a – general view, b – assembly node using a screw connection: 1, 2 – connected C-sections, 3 – screw, 4 – nut, 5 – sleeve

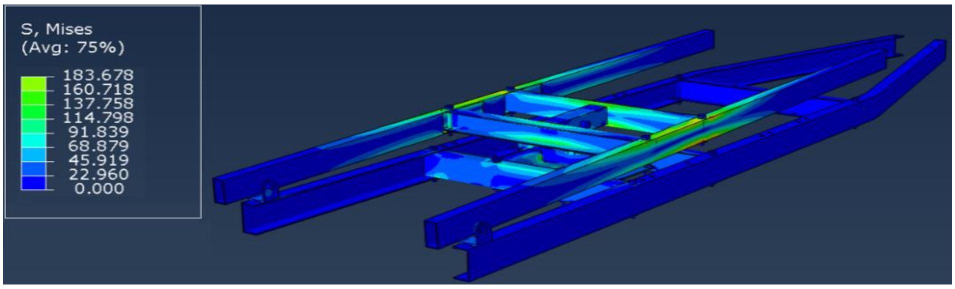


Fig. 3. Stress distribution in a solid model of frames made by bolted connections

The FEM strength analysis was carried out at the time of initiation of the load box lifting process. The stress distributions in the frame assembly are shown in Figure 3 and Figure 4 shows the distribution of stresses in the cylinder mounting actuator node

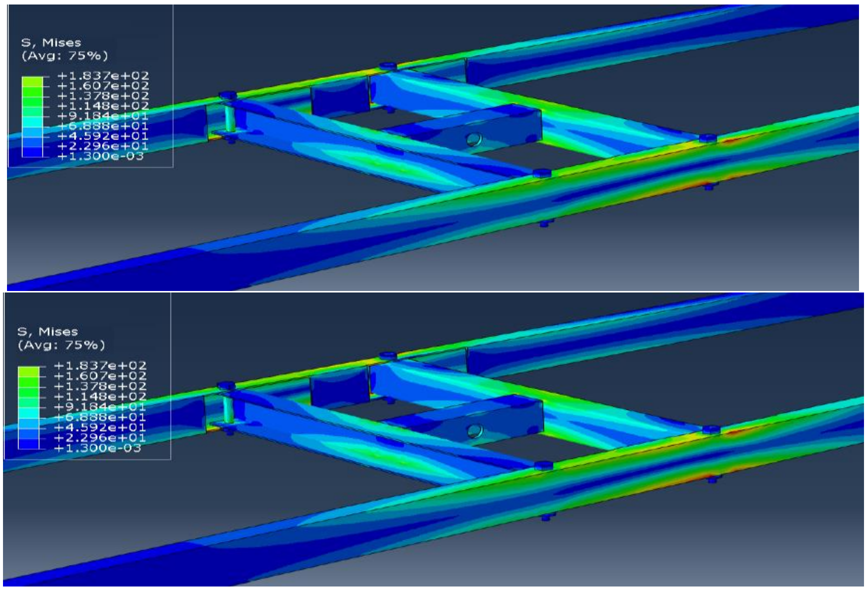


Fig. 4. Stress distribution in the cylinder mounting nodes: a) in the upper frame, b) in the lower frame

The maximum stresses are generated on the upper surfaces of the side members and crossbeams of the upper frame and reach the value of 183 MPa. This condition is typical for a model of a bending beam subjected to a continuous load along its entire length. Lifting the load box causes the actuator to take over the load resulting from the weight of the load, and the resulting reaction forces concentrate on the sockets that are the support areas of the lifting unit. High-stress values in these areas also result from the small contact area – the thickness of the beam walls is 4 mm. It should be noted that the high values of compressive stresses arising in the sleeves mounted on the connecting bolts – they reach a value of approx. 120 MPa.

The strength analysis of the original semi-trailer frame made in the bolted connection technology was aimed at identifying the places of maximum stress. These places will be treated as a reference during strength analyses of frames made in different assembly technologies.

3.2. The construction of frames made in welding technology

The distribution of stresses in the frame assembly is shown in Fig. 5. It should be noted that the stress maps are identical to those in the bolted frames (Fig. 3, 4) despite the use of other beam profiles (see sections 3.4.1 and 3.4.2), with a decrease in the value of the maximum stresses (to 169 MPa) reduced by approx. 15 MPa. The most heavily loaded elements in the upper and lower frames are the hydraulic cylinder mounting sockets (Fig. 6, items 1, 2) made in channel sections. The next surfaces where comparable reduced stresses are recorded are the upper and lower planes of the stringer and crossbeam of the upper frame. Maximum stresses occur in the middle of its length (Fig. 6, item 3).

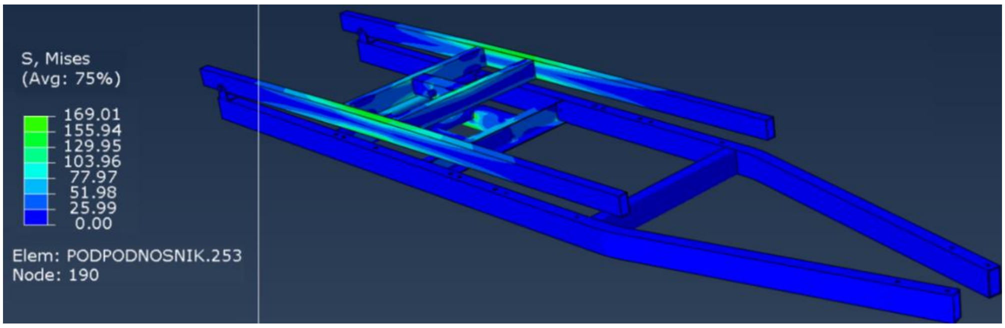


Fig. 5. Stress maps on the assembly of trailer frames made by welding

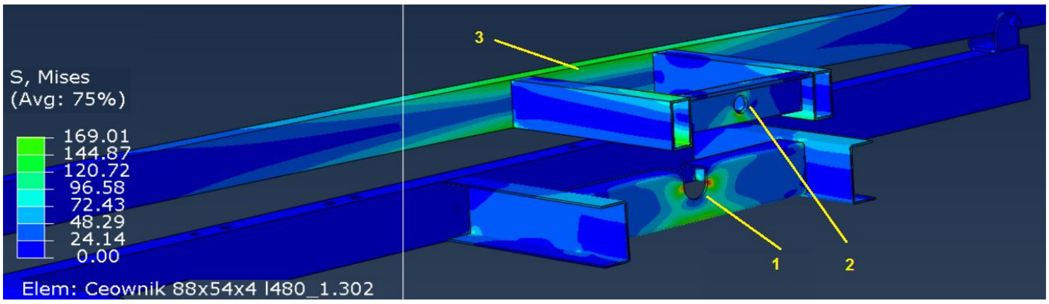


Fig. 6. The place of maximum stress in the lower frame – the cylinder socket: 1 – actuator mounting location in the lower frame, 2 – cylinder mounting hole in the upper frame, 3 – structural element of the upper frame

3.3. The Construction of frames made in riveting technology

Another modification entails connecting steel profiles with blind rivets. The use of the riveting machine made it necessary to change the profiles of the crossbeams and longitudinal beams of the upper and lower frames forming the cylinder mounting nodes (see section 3.4.3). Rivets with an outer diameter of 6.4 mm made of stainless steel A2 [3] were used to connect the frame elements. Three rivets were used in each fastening node (Fig. 7, item 1, 2). They have been arranged so that the production worker is able to fit a pneumatic riveter with a standard head diameter.

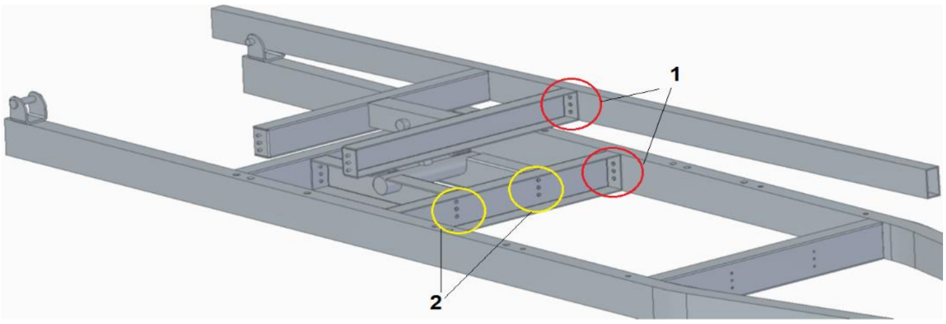


Fig. 7**.** Trailer frame made with the use of riveted connections: 1 – connecting the crossbeams to the stringers, 2 – connecting the longitudinal beams of the cylinder mounting node to the crossbeam

The strength analysis was also carried out for the situation where the angle between the upper and lower frames was 1.5°. The distribution of stresses on the stringers and crossbeams of the upper frame and in the sockets of the cylinders are identical to those in the bolted and welded frame, but the maximum values of reduced stresses are not observed here – Fig. 8

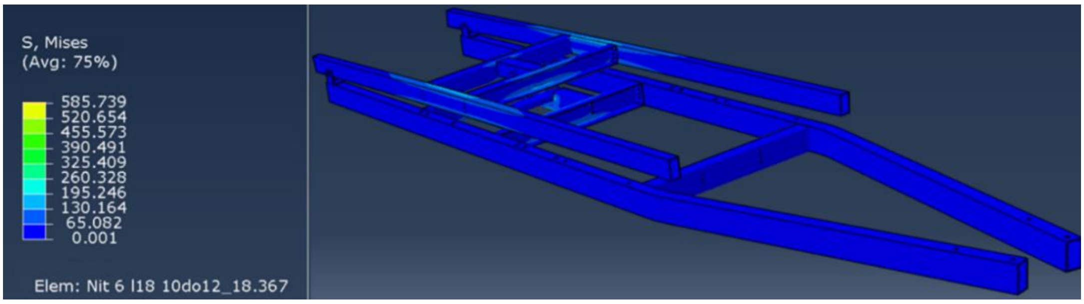
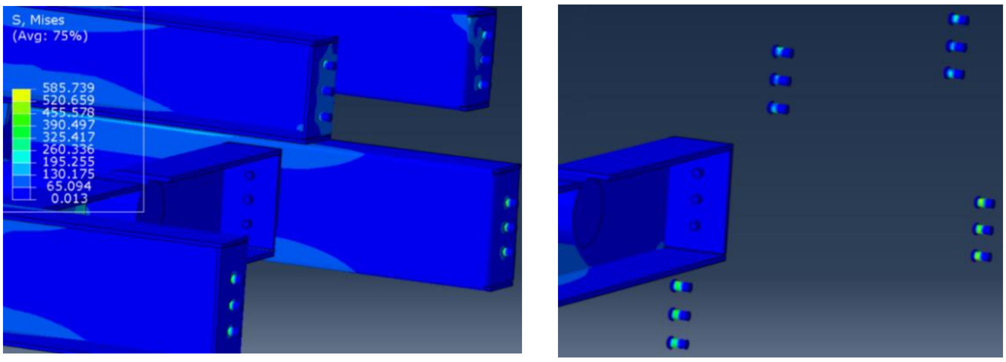


Fig. 8. Stress maps on the assembly of trailer frames made by riveting

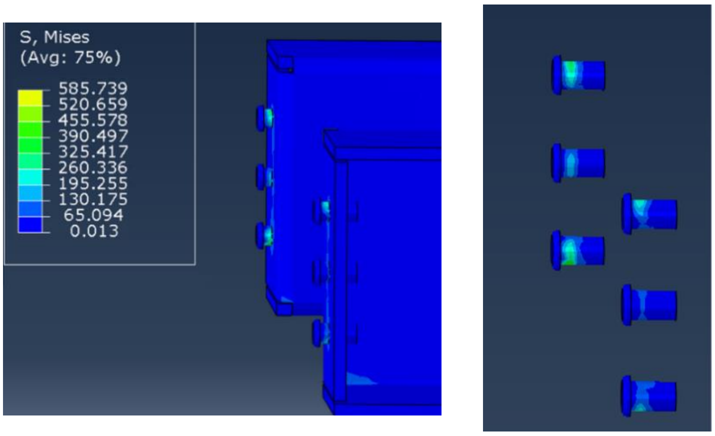
On the cylindrical surfaces of the rivets, the stresses caused by shear and surface pressures reach the value of σ = 585 MPa (Fig. 8, 9). The rivet material has a yield strength of Re = 450 MPa. Therefore, the possibility of changing the frame production technology by joining with bolts and nuts for riveting should be rejected. The rivet is a critical element that determines the strength of the structure.



(a) **(b)**

Fig. 9. Distribution of stresses in rivet nodes: (a) stresses in the rivets fixing the crossbeams to the longitudinal members of the upper and lower frames (Fig. 7, area 1); (b) view with hidden longitudinal beams

Below is a list of profiles used to make the lower and upper frames in three assembly technologies. It was assumed that the cost of making the loading box, the drawbar, and the cost of purchasing the complete axle remain unchanged. Dimensions of U-shaped and rectangular sections, sheets and standard parts, as well as their prices, were taken from sources [24-27]. The costs of works related to laser cutting, riveting and welding are approximate costs estimated on the basis of information contained in [6, 21].

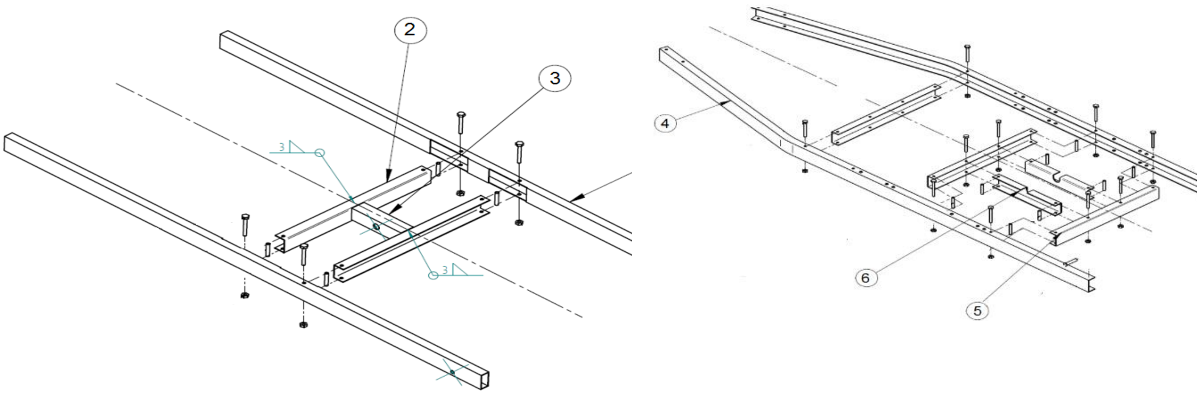


(**a**) (**b**)

Fig. 10. Distribution of stresses in rivet nodes: (a) stresses in the rivets connecting the cross-beams with the lifting elements (Fig. 7, area 2); (b) view with hidden crossbeams

3.4.1. Original frame

Figure 11 shows the upper and lower frames made in the technology of screw joints. Table 1 presents a list of materials needed for the production of car trailer frames made in the technology of bolting.



(**a**) (**b**)

Fig. 11. The frame made in connection technology with the use of bolts and nuts: (a) upper frame; (b) Lower frame. The beam numbers on the references correspond to the ordinal numbers in Tab. 1

The elements listed in table 1 marked with the order number 2, 5, 6 will be made of sheet metal. The following sheets can be used for production:

- 3 mm thick sheet, dimensions 1 x 2 [m] – sheet price: EUR 81.2,
- 4 mm thick sheet – sheet size 1 x 2 [m] – sheet price: EUR 96.15.

Dimensional analysis indicates that half a sheet of 3 mm thick and 4 mm thick should be used. So the cost of the material will be 88.67 EUR.

The cost of laser cutting depends on the thickness of the sheet:
- 3 mm thick sheet, dimensions – 2.14 EUR/mr,
- 4 mm thick sheet dimensions – 3.85 EUR/mr.

Tab. 1
List of materials needed for the production of frames made in the technology of bolting

No.	Element	Dimensions [mm]	Length [mm]	Quantity	Unit price [€/mr]	Value [€]
	Upper frame					
1 2 3	Rectangular section profile	80x40x3	2520	2	7.70	38.80
	C-section profile	74x50x3	711	2	Made of sheet metal	
	C-profile	60x40x4	260	1	5.76	1.50
Lower frame						
4	C-profile	100x50x4	3600	2	11.75	84.60
5	C-section profile	86x54x4	700	3	Made of sheet metal	
6	C-section profile	80x54x4	480	2	Made of sheet metal	
Connecting elements						
7	Bolt M8 x100			4	0.96	3.84
8	Bolt M8 x120			4	1.00	4.00
9	Bolt M8 x150			6	1.35	8.10
10	Nut M8			14	0.14	1.96
11	Pad 8.2			14		0.21
12	Tube	ϕ14	1024	1	2.84	2.90

The total cutting cost will be EUR 21.80.

The cost of bending profiles on a press brake is calculated on the basis of an employee's hourly rate of EUR 8.55/h, which can be estimated at EUR 4.27.

Table. 2 presents a breakdown of the labour costs of an employee on the assembly line of car trailers.

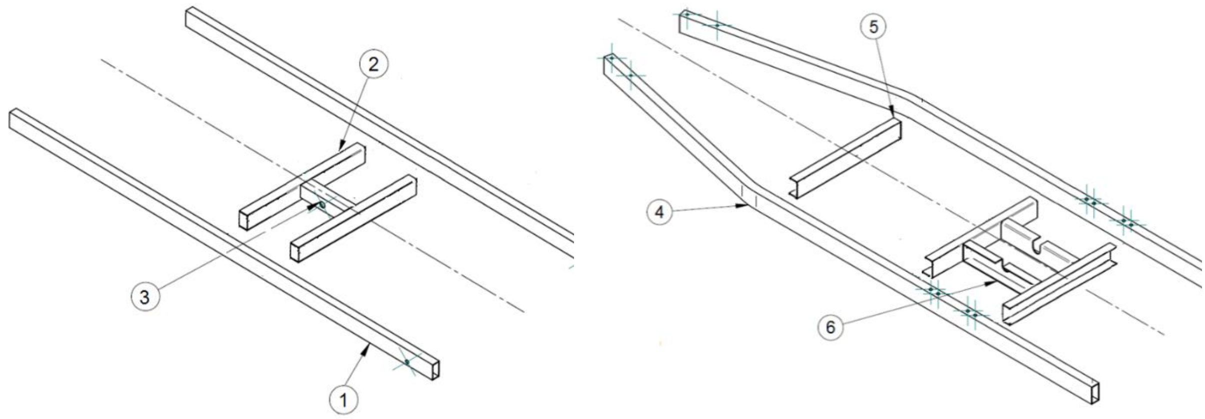
Tab. 2
A breakdown of the labour cost of a worker on an assembly line

Number of bolted connections	Time of completion and assembly of the connection [min]	Employee rate [€/h]	Total costs in €
14	12	6.40	1.28

To sum up: the total cost of making the frames using bolting technology is EUR 262.00.

3.4.2. Welding frame

Figure 12 shows the upper and lower frames made by welding.



(**a**) (**b**)

Fig. 12. The frame made in welding technology: (a) upper frame; (b) lower frame. The beam numbers on the references correspond to the ordinal numbers in Tab. 3

Table 3 presents a list of materials needed for the production of car trailer frames made in the welding technology. Table. 4 presents a breakdown of the welder's labour costs on the assembly line of car trailers.

Tab. 3

List of materials needed for the production of frames made in the welding technology

No.	Element	Dimensions [mm]	Length [mm]	Quantity	Unit price [€/mr]	Value [€]
	Upper frame					
1 2 3	Rectangular section profile	80x40x3	2520	2	7.70	38.90
	Rectangular section profile	80x40x4	711	2	8.54	12.18
	C-profile	60x40x4	260	1	5.77	1.50
Lower frame						
4	Rectangular section profile	100x50x4	3600	2	12.80	92.20
5	C-profile	100x50x3	700	3	9.00	18.90
6	C-profile	88x54x4	480	2	9.82	9.40

Tab. 4

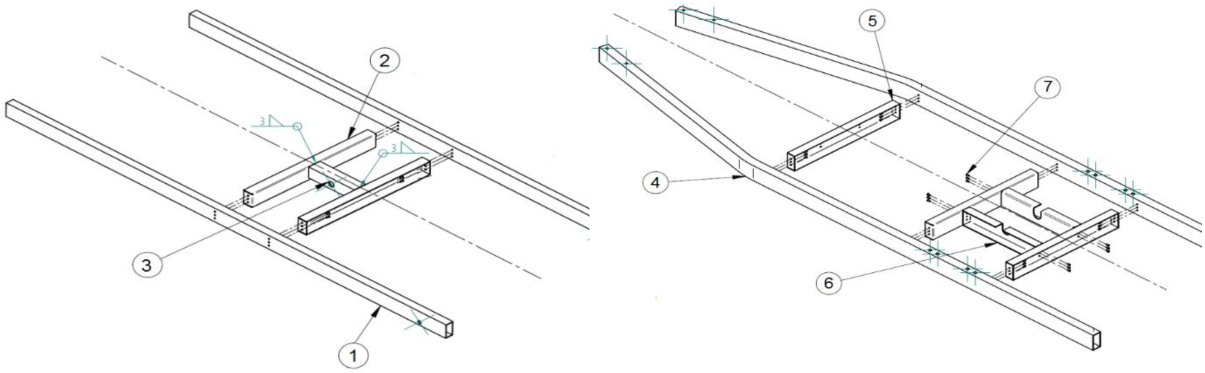
List of the cost of the welder's work

Weld length [mm]	Welder rate [€/mm]	Total costs in €
2904	0.032	93.00

To sum up: the total cost of making the frames in the welding technology is EUR 266.20.

3.4.3. Riveted frame

Figure 13 shows the upper and lower frames made in the riveting technology. Table 5 presents a list of materials needed for the production of car trailer frames made in riveting technology.



(**a**) (**b**)

Fig. 13. The frame made in riveting technology: (a) upper frame; (b) lower frame. The beam numbers on the references correspond to the ordinal numbers in Tab. 5

Tab. 5

List of materials needed for the production of frames made in riveting technology

No.	Element	Dimensions [mm]	Length [mm]	Quantity	Unit price [€/mr]	Value [€]
	Upper frame					
1	Rectangular section profile	80x40x3	2520	2	7.70	38.90
2	C-section profile	80x50x3	711	2	Made of sheet metal	
3	C-profile	60x40x4	260	1	5.77	1.50
Lower frame						
4	Rectangular section profile	100x50x4	3600	2	12.80	9.18
5	C-section profile	100x50x3	700	3	Made of sheet metal	
6	C-section profile	100x50x4	480	2	Made of sheet metal	
7	Rivet			42	0.021	0.90

The elements listed in the table marked with the order number 2, 5, 6 will be made of sheet metal. Dimensions of metal sheets and their prices are given in point 2.1.

Dimensional analysis shows that half a sheet of each plate can be used to make profiles intended for the production of one lower and upper frame. So the cost of the material will be EUR 88.67. The total measurement of the perimeter of individual profiles cut from 3 and 4 mm thick metal sheets multiplied by the unit cost of laser cutting allows you to calculate the cost of this technological operation. Its value is EUR 33.12.

The cost of bending profiles on the press brake is calculated on the basis of the employee's hourly rate and is EUR 8.55/h. This cost can be estimated at EUR 4.28.

Table. 6 presents a breakdown of labour costs of a production worker.

Tab. 6

A breakdown of the labour cost of a production worker

Number of riveted connections	Time of completion and assembly of the connection [min]	Employee rate [€/h]	Total costs in €
42	10	6.40	1.10

To sum up: the total cost of riveted frames for one car trailer is EUR 177.80.

Figure 14 shows a chart with a summary of car trailer production costs for individual assembly technologies.

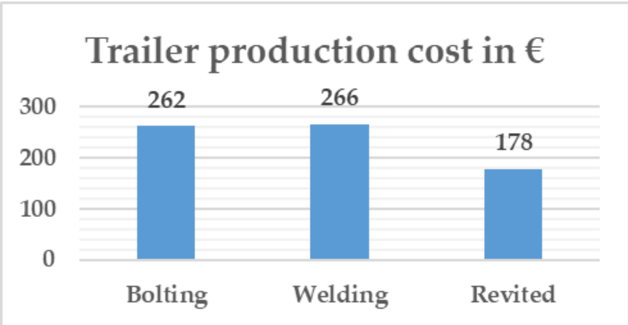


Fig. 14**.** Production costs of the trailer in three production technologies

As can be seen from the summary presented in Figure 14, the lowest production costs of the car trailer occurs for the riveting technology. However, in the case of the other two variants, the costs are at a similar level of about EUR 265.

Finally, it should be added that the method of protecting the frame against corrosion depends on the assembly technology. Small elements intended for screwing and riveting can be covered, for example, with a zinc coating individually, before joining. Each of the frames, separately upper and lower, should be galvanized in their entirety if they are welded. This may result in slight variations in electroplating costs, which are not considered here. In addition, A2 steel rivets should not be used to connect non-alloy steel components, but if popular blind rivets are used, their strength is insufficient.

4. CONCLUSIONS

The aim of the research work was to indicate whether it is possible to change the production technology of the load-carrying system of a self-dumping car trailer. For this purpose, solid models of frames made during the process of riveting, bolting, and welding were made, and a strength analysis was carried out using FEM. The next step was to prepare technical documentation containing lists of beams of the upper and lower frames, indicating whether they are standard profiles or made of sheet metal.

In each of the three versions of the frames, the highest stress values are generated in the upper frame on the stringers and in the crossbeams. Another area of maximum stress is the cylinder pin mounting slots in the upper and lower frames. However, in the case of a riveted frame, the strength-critical elements are the rivets. The use of three rivets with a diameter of 6.4 mm in each assembly node causes that the stresses caused by shear are exceeded in their material. This situation is also caused by the small wall thickness of the joined profiles, which is 4 mm. Making the frames in the welding process can be an alternative method of production in relation to the original frame of the trailer. The implementation cost is close. It should be noted here that in the case of welded frames, all beams are made of standard profiles. The need to make beams by laser cutting from sheet metal and bending on the press brake is eliminated. In the case of riveted frames, their production cost is the lowest, by about 1/3 compared to the cost of welded and bolted frames. The cost is low, although it is necessary to make three beams yourself.

References

1. Barta D., J. Dižo, M. Blatnický, D. Molnár. "Experimental research of vibrational properties of a single-axle trailer when crossing an individual road obstacle". 2022. *Strojnícky Časopis – Journal of Mechanical Engineering* 72(3): 19-26.
2. De Bernardis M., G. Rini, F. Bottiglione, A.E. Hartavi, A. Sorniotti. 2023. "On nonlinear model predictive direct yaw moment control for trailer sway mitigation". *Veh. Syst. Dyn*. 61(2): 445-471. DOI: 10.1080/00423114.2022.2054352.
3. DIN 7337: 1991. *Blind rivets with break mandrel*.
4. Dižo J., M. Blatnický, R. Melnik, S. Semenov, E. Mikhailov, J. Kurtulik. 2022. "Static analysis of tipping superstructure of single-axle tractor trailer". In: *Engineering for rural development*, Jelgava, 25.-27.05.2022. DOI: 10.22616/ERDev.2022.21.TF003.
5. Gnap J., J. Jagelčák, P. Marienka, M. Frančák, M. Kostrzewski. 2021. "Application of mems sensors for evaluation of the dynamics for cargo securing on road vehicles". *Sensors* 21(8): 2881.
6. *Welding – definition, types and valuation*. Available at: https://allweld.pl/spawanie-i-spawalnictwo.
7. *Bobrek*. Available at: https://bobrek.pl/.
8. *Manufacturer of pipes, profiles and steel structures.* Available at: https://www.stalimpex.eu.
9. *Stawex*. Available at: http://www.stawex.com.pl/.
10. Ibrahim A.M., A.M. Ali, H. Kamel. 2023. "Design optimization and production of a small-scale semi-trailer chassis for testing". *J. Eng. Appl. Sci*. 70: 35. DOI: 10.1186/s44147-023-00201-z.
11. Jagelčák, J., M. Kiktová, M. Frančák. 2020. "The analysis of manoeuvrability of semi-trailer vehicle combination". *Transp. Res. Proc*. 44: 176-181.
12. Kulikowski K., Z. Kamiński. 2019. "Methods for improving the dynamic properties of the air braking systems of low-speed agricultural trailers". *Arch. Automot. Eng*. 84(2): 5-22. DOI: 10.14669/AM.VOL84.ART1.
13. Ladra P., B. Posiadała. 2018. "Strength Analysis of the Multi-tasking Car Trailer". In: Rusiński E., D. Pietrusiak (eds). Proceedings of the 14th International Scientific Conference: Computer Aided Engineering. CAE 2018. *Lecture Notes in Mechanical Engineering*. Springer, Cham. 2019. P. 419-426. DOI: 10.1007/978-3-030-04975-1_49.

14. Ladra P., B. Posiadała. 2018. “Modeling and strength analysis of the prototype of the multi-tasking car trailer”. *MATEC Web Conf*. 157: 01014.
15. Ladra P., B. Posiadała. 2016. “Modeling and strength analysis of the specialized car trailer”. In: *Proceedings of the 13th International Scientific Conference*: 313-321.
16. Lodwik D., J. Pietrzyk. 2018. “Analysis of the structure of the frame of a trailer for transport of bales of compressed straw in the aspect of minimization of materials and energy consumption”. In: *3rd International Conference on Energy and Environmental Protection, E3S Web Conf. 46*: 00005. DOI: 10.1051/e3sconf/20184600005.
17. Marienka P., M. Frančák, J. Jagelčák, F. Synák. 2020. ”Comparison of braking characteristics of solo vehicle and selected types of vehicle combinations”. *Transp. Res. Proc*. 44: 40-46.
18. Mokričková L., V. Rievaj. 2016. “Position of the centre of gravity and driveability of the vehicle”. *LOGI Sci. J. Transp. Logist*. 7: 108-115.
19. Plöchl M., P. Lugner. 1999. “ Passenger car and passenger car-trailer – different tasks for the driver”. *JSAE Review* 20(4): 543-548. DOI: 10.1016/S0389-4304(99)00036-3.
20. Sagi R., A. Racotch, D. Wolf. 1973. “Theoretical considerations in placing the centre of gravity of single-axled trailers”. *J. Agric. Eng. Res.* 18(2): 159-165.
21. Schuh G., C. Kelzenberg, J. Wiese. 2019. ”Design model for the cost calculation of product-service systems in single and small series production”. *Procedia CIRP* 84: 296-301. DOI: 10.1016/j.procir.2019.04.216.
22. Skrúcaný T., J. Vrábel, M. Kendra, P. Kažimír. 2017. ”Impact of Cargo Distribution on the Vehicle Flatback on Braking Distance in Road Freight”. In: *18th International Scietific Conference – LOGI 2017, MATEC Web Conf.* 134: 00054. DOI: 10.1051/matecconf/201713400054.
23. Viano D.C., C.S. Parenteau. 2022. “Significance of tractor-trailer impacts to the rear of light vehicles”. *Traffic Inj. Prev*. 23(4): 169-175.
24. Vrabel J., T. Skrucany, L. Bartuska, J. Koprna. 2019. “Movement analysis of the semitrailer with the tank-container at hard braking - the case study”. *IOP Conf. Ser. Mater. Sci. Eng*. 710(1): 0120254.
25. Wang G.L., Y.H. Lu. 2006. “Braking stability analysis of car-trailer”. *Journal of Jiangsu University* 27(2): 130-132.
26. Figlus Tomasz, Lukasz Kuczyński. 2018. "Selection of a semi-trailer for the haulage of long oversize loads, taking into account an analysis of operational damage". In: *11th International Science and Technical Conference Automotive Safety*: 1-5.
27. Zamecnik J., J. Jagelcak. 2015. “Evaluation of wagon impact tests by various measuring equipment and influence of impacts on cargo stability”. *Commun. Sci. Lett. Univ. Zilina* 17(4): 21-27. DOI: 10.26552/com.C.2015.4.21-27.
28. Zhang N., J.-H. Wu, T. Li, Z-Q. Zhao, G.-D. Yin. 2021. “Influence of braking on dynamic stability of car-trailer combinations”. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering* 235(2-3): 455-464. DOI: 10.1177/0954407020959895.
29. Zhang N., G. Yin, T. Mi, X. Li, N. Chen. 2017. ”Analysis of dynamic stability of car-trailer combinations with nonlinear damper properties”. *Procedia IUTAM* 22: 251-258.

Received 29.02.2024; accepted in revised form 07.04.2024