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SELECTED ISSUES FROM THE ANALYSIS OF COMPOSITE VEHICLE BODIES

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Abstract – Issues related to designing support frames and bodies for electric delivery vehicles (eVans) are the topic discussed by engineers around the world. Design processes are based on classic solution models which use structural steel profiles. Directions for development include the production of highly tensile steel frames with increased strength parameters. The authors of the article designed and constructed a prototype polymer body for a delivery vehicle. They conducted detailed multi-variant numerical analyses on the prototype and preliminary experimental tests. The obtained results clearly confirmed the correctness of the formulated thesis about the possibility of designing bodies made of structural plastics dedicated to electric vehicles. For a static-loaded parts of structure uniform stress distribution without concentration, with maximum stress value of 25 MPa was achived. For parts of structure carrying dynamic loads shape-derived stress concentration is inevitable. Nevertheless, the stress level of 96 MPa is within the limits of strength, due to the velocity-dependent material properties.

Key words – vehicle support frame, transport body, delivery vehicle, eVan, composite materials

JEL Classification – 031, 032

INTRODUCTION

Economic development in industrialized countries, in particular the issue of delivering goods to the end recipient, is based on the use of delivery vehicles. Transport logistics involves the movement of goods to distribution centers using lorries, and then local distribution using delivery vehicles. One can notice a dynamic growth of the electric delivery vehicles segment, the so-called eVans. This fact is primarily driven by the need to distribute goods in urban agglomerations with ever more frequently introduced entry restrictions for diesel-powered vehicles. The current solutions for electric delivery vehicles are based on traditional constructions whose power units have been modified. Such an approach, however, is an interim solution. Bearing in mind questions related to the powertrain and power supply of electric vehicles, in particular delivery vehicles, design solutions developed for traditionally-powered vehicles cannot be effectively used in eVans [1]. It is, therefore, necessary to initiate design work aimed at developing new structures of support frames and bodies dedicated to electric delivery vehicles. The aim of the work was to verify the feasibility of designing and manufacturing a transport frame for a delivery vehicle using generally available technologies and industrial composite materials. All the work was done with the use of solutions in electric vehicles in mind.

1. DESIGN SOLUTIONS FOR DELIVERY VEHICLES

The body style solutions considered in this article are intended for delivery vehicles, which are designed and constructed mainly for the carriage of goods and having a mass not exceeding 3.5 tonnes. The indicated vehicles are classified as "lorries" with code BA, category N1 according to Directive 2007/46 [1]. Unlike vans (code BB), where the driver and the loading area are within one unit, the cargo space in goods vehicles is completely separated from the passenger space. Delivery vehicles available on the market come in three principal body configurations: Van type, open type and box type. The differences between the body types are shown in Figure 1.

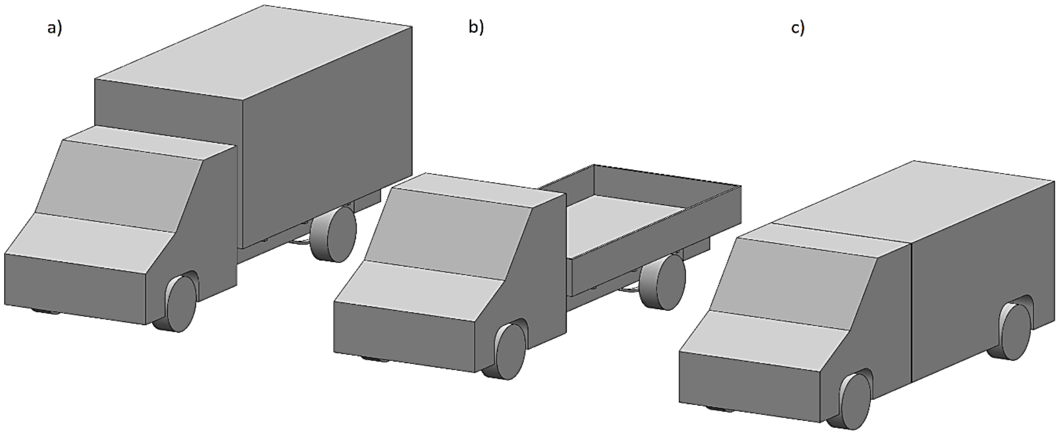

Fig. 1. Delivery vehicle body types: a - box body, b – open body, c - van body

Van type bodies are an integral unit and are made by vehicle producers (complete vehicles). Structurally similar to each other, open and box bodies are usually the vehicle's additional element that requires assembly and approval [2-4]. In such a case, the vehicle, before body assembly, obtains the "chassis-cab" type approval with code BX. Often such adaptations are made by entities that are independent of vehicle manufacturers. Such bodies can be mounted most often on vehicles with a structurally independent frame.

The article focuses on the construction of vehicle support frames which can be adapted for the open transport body [5-6]. A support frame is the basic structural element of vehicles. Due to its properties, it integrates suspension and powertrain elements and other electromechanical systems of vehicles. It allows to transfer working loads resulting from the movement of the vehicle and weight of carried goods which are transmitted through the transport body frame [7]. A support frame is intended to ensure sufficient strength, guarantee flexural rigidity and torsional stiffness defined for a particular vehicle, and perform the utility function by assembling a transport body [8].

A vehicle frame performs the supporting function for the vehicle's transport body. The differences between a support frame and a body frame are shown in Figure 6. The structure of a transport body considered in the article was designed for a delivery vehicle with an independent frame. The structure of a vehicle is based on a ladder frame, to which suspension elements, powertrain and the driver and passenger compartment are attached. A ladder frame consists of two longitudinal beams connected by crossbeams. The diagram of a vehicle equipped with a ladder frame is shown in Figure 2.

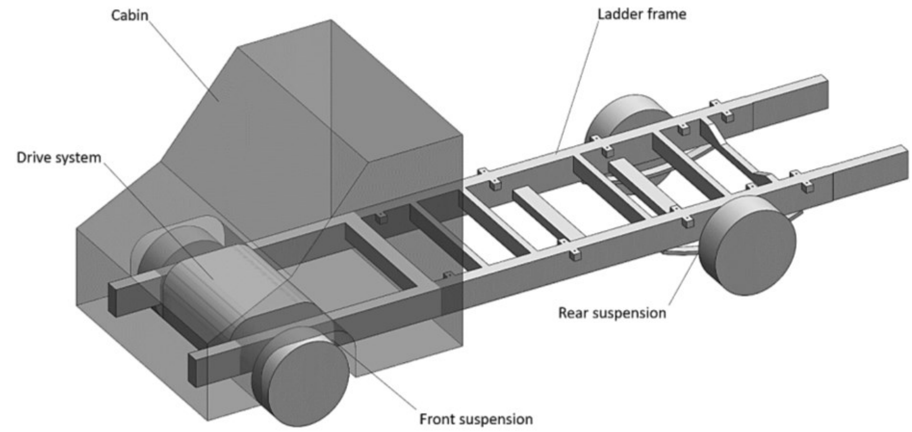

Fig. 2. Diagram of the structure of a vehicle with an independent support frame, without a transport body installed

The presented solution offers high strength and resistance to torsion and bending, provides freedom in designing a utility body, and at the same time determines the minimum height at which a floor plate can be found.

2. Construction methods

The production of a frame is based on cold forming technologies. The desired rigidity and strength are obtained by the spatial shaping of sheet metal in order to obtain thin-walled profiles. The beams of support frames, depending on the complexity of structure geometry, can be bent or pressed. They can come as open or closed profiles and can be joined by welding or fusing [9-11]. Figure 3 shows examples of shapes of support frame profiles.

In the analyzed vehicle, the manufacturer used a c-type profile to make longitudinal beams, as shown in Figure 3. The use of a structural profile in the actual body is shown in Figure 7/designated as D/.

The current technology used for the production of electric batteries does not yet allow to obtain energy accumulation efficiency comparable to traditional solutions [2]. This means that electric batteries will be heavier and will take up more space in a vehicle compared to a traditional liquid or gaseous fuel tank. The structural solutions of support frames developed for electric vehicles aim to reduce the weight of a frame. The direction of work is intended to lower energy demand [11].

The basic construction material includes steels [9 - 11]. Their use is justified by a favourable price-to-mechanical parameters ratio. In order to reduce the total weight of a support frame, structural modifications are introduced to increase the degree of tension [12]. Examples of standard solutions and modifications are shown in Figures 4 and 5.

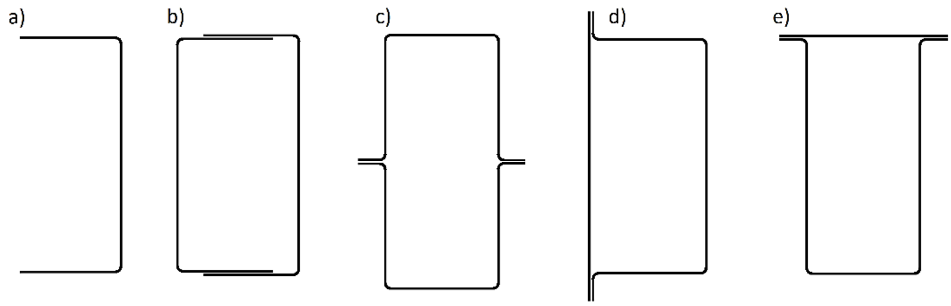

Fig. 3. Types of profiles most often used for the construction of longitudinal beams of independent support frames in delivery vehicles and lorries. A – c-beam, B – double c-beam, C - double hat profile, D – hat profile closed with flat plate on the side, E – hat profile closed with flat plate on top

Fig. 4. Standard solution of a support frame on the example of a Fiat Ducato delivery vehicle [13]

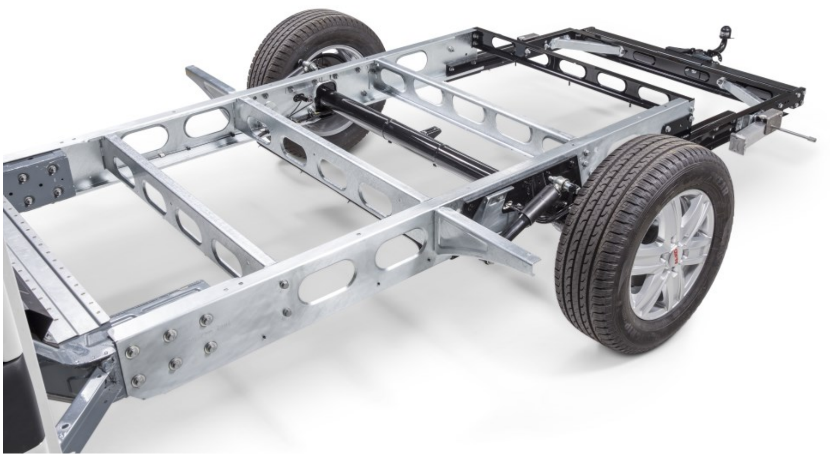

Fig. 5. Example of a support frame modification [14]

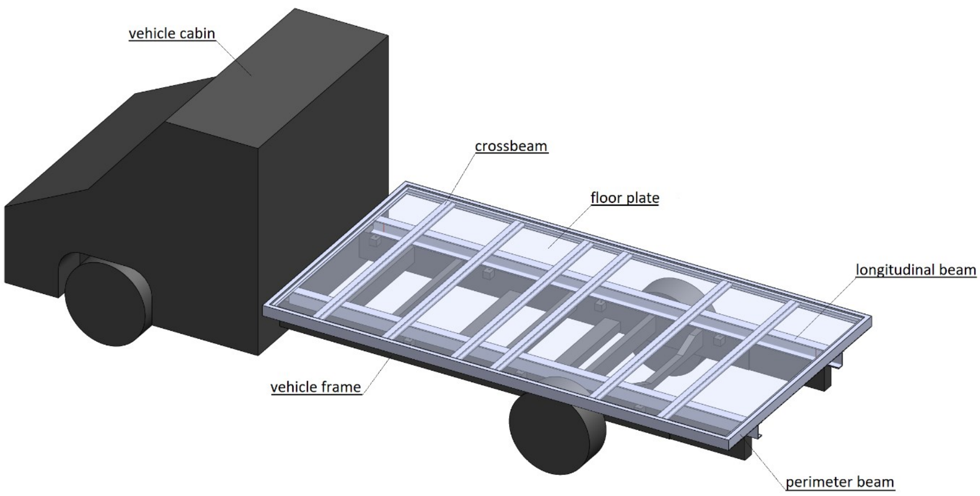

Fig. 6. Diagram of the structure of a classic frame body's floor plate

On the basis of commercial information [13-14] obtained from leading manufacturers of support frames for vans, e.g. the AL-KO company, the current development and modifications of independent support frames of vans include the modification of structure geometry [15-16]. It has been found that currently no work is being undertaken on the use of new materials [17-18].

3. DESIGN ISSUES RELATED TO DELIVERY VEHICLE BODIES

In order for a delivery vehicle to perform its utility function, it must be equipped with a cargo space. Classic transport bodies of delivery vehicles weighing less than 3.5 tonnes are made of dedicated drawn aluminum profiles of the shape shown in Figure 8, forming a joist structure supporting the floor plate, usually made of laminated wood-based materials. The borders of the floor frame are clad with perimeter profiles, as shown in Figure 8b. Sideboards and other structure supporting elements protecting the cargo with tarpaulin are attached to the prepared floor structure. Connections of structural elements are made by welding or special, shaped threaded connections.

The diagram of the aluminum structure of the body's floor frame is shown in Figure 6. The actual solution of a classic structure of the aluminum body's floor frame is shown in Figure 7.

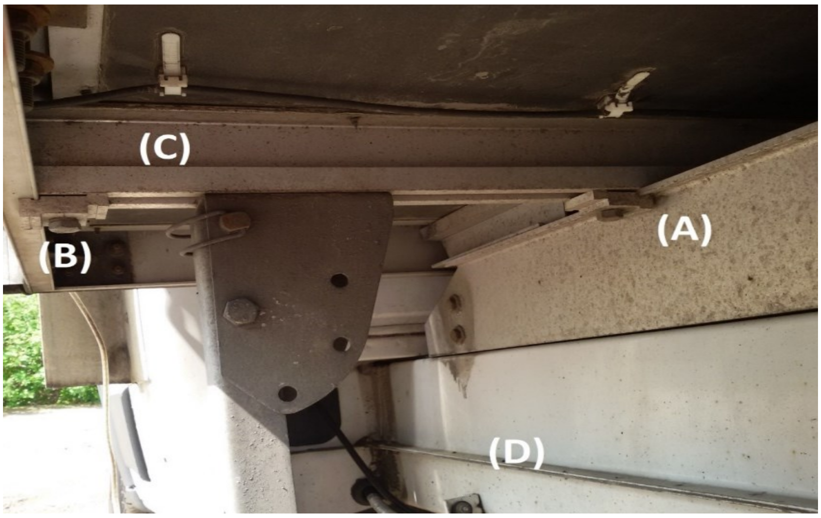

Fig. 7. Example of a body design solution in a Fiat Ducato. A - longitudinal beam of the body frame, B - perimeter beams, C - crossbeam, D – side member of the vehicle support frame. Visible threaded connections of elements

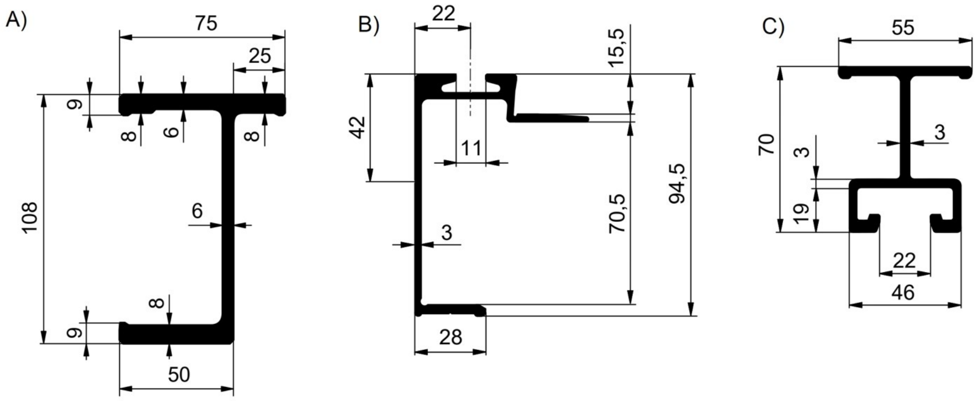

Fig. 8. Examples of cross sections of structural aluminum profiles A - longitudinal beam, B - perimeter beam, C - crossbeam

4. NEW APPROACH TO THE DESIGN OF VEHICLE BODIES

The authors of the article verified the structure and carried out detailed numerical analyses of a vehicle body made of structural aluminum alloy profiles shown in Figure 6. They assessed the identified phenomena occurring during the operation of a vehicle support frame and body. The work uses the information contained in [19-24]. On this basis, they concluded that it is possible to replace structural aluminum alloys with composite support structures, which is in line with the conclusions of the analyzes published in [25-26].

The authors noticed that in the case of a classic frame body, the area of the structure tension is limited to the immediate zone of influence of the forces resulting from cargo weight. The authors of the articles dealt with the issues [27-29]. As a consequence, the strength of the entire structure is determined by local phenomena, the occurrence of which depends on the location of cargo in the cargo space.

A new approach to designing solutions for delivery vehicle bodies was proposed. Based on commercial construction profiles and grating plates, the authors designed composite support structures dedicated to being used in the construction of delivery vehicle bodies (Fig. 9). The profiles are made by means of technologies such as fibre pultrusion and glass mats in polyester resin. The construction grating support plates are manufactured in die-cut molds. For the purpose of research, a prototype of the solution was made that met functional and utility assumptions (Fig. 10).

The proposed solution is not a classic frame structure. The use of grating plates in the composite body made it possible to adjust the rigidity of the body to the determined values of operational loads.

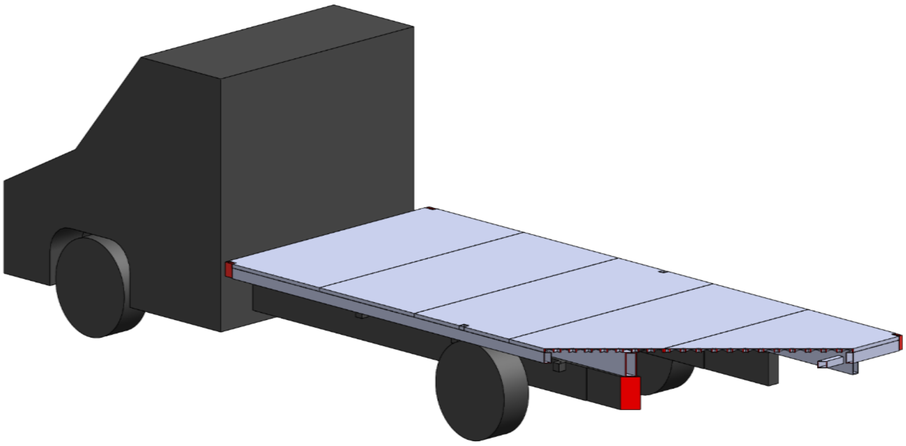

Fig. 9. Diagram of the floor plate construction of the composite body (the cross section shows how to use a composite grating)

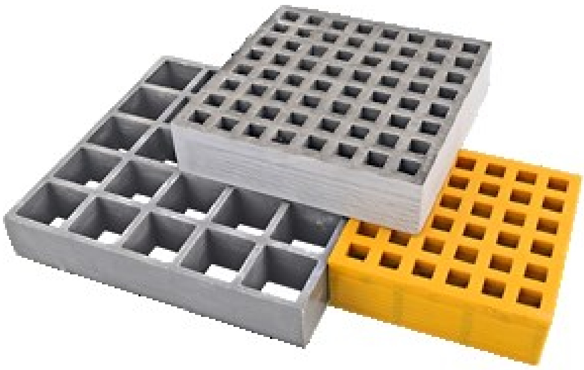

Fig. 10. Example of commercial composite gratings

5. Analysis of the frame and open platform made of composite materials

The design solution of the original composite vehicle body is based on the use of commercially available composite grating plates that enable to obtain a homogeneous structure of the cargo area floor plate. Longitudinal beams (side members) were attached directly to the vehicle's support frame. The floor plate was placed on composite longitudinal beams. The height of the beams was the subject of reflections due to the necessity to ensure clearance in the rear suspension system of the vehicle, the location of the centre of gravity of the body and stability, in particular in a curved motion. The floor plate is framed with peripheral profiles, to which integral elements of the body - elements of the support structure of tarpaulin covering the cargo and sides - are attached. The designed solution is dedicated to electric delivery vehicles, the so-called eVans. The model of the designed composite body is shown in Figure 11, the profiles used in are shown in Figures 12-14, and the composite support grating panel in Figure 15.

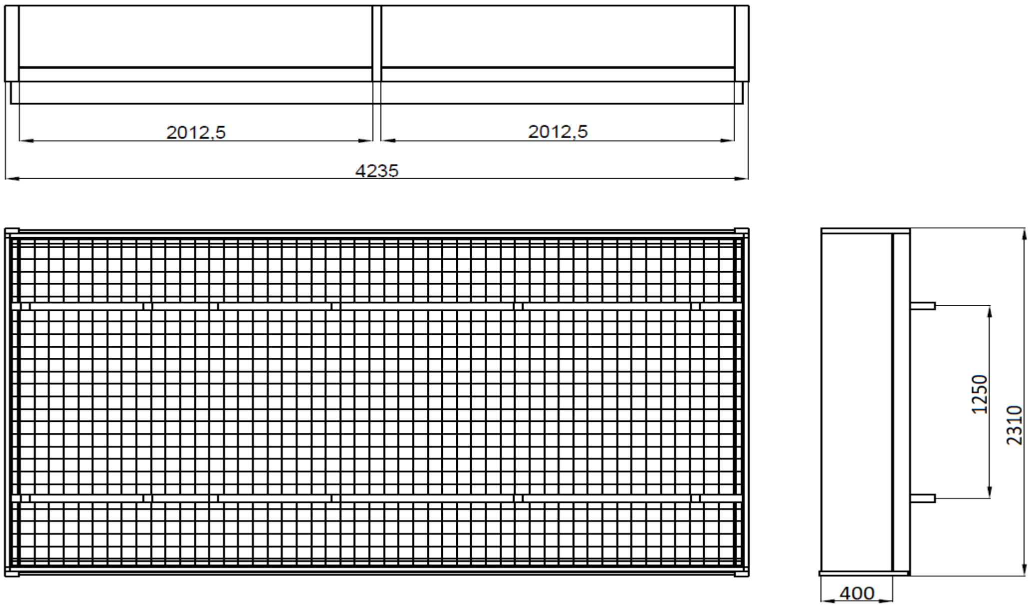

Fig. 11. Structural model of the open body designed on the basis of a grating plate

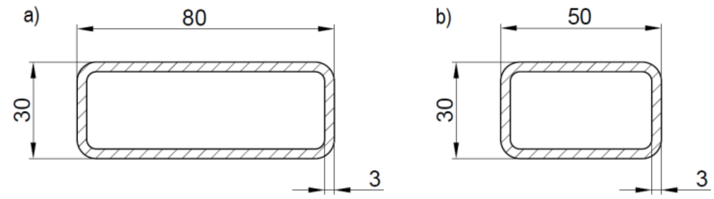

Fig. 12. Cross-sections of support pillars of the open body. a/ corner, b/ middle

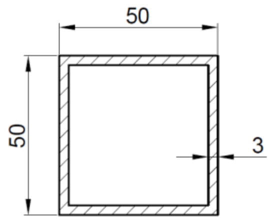

Fig. 13. Cross-section of a beam that strengthens the fastening of the central pillar

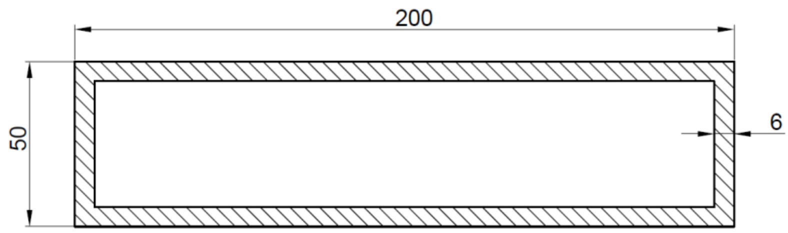

Fig. 14. Cross-section of the longitudinal beam

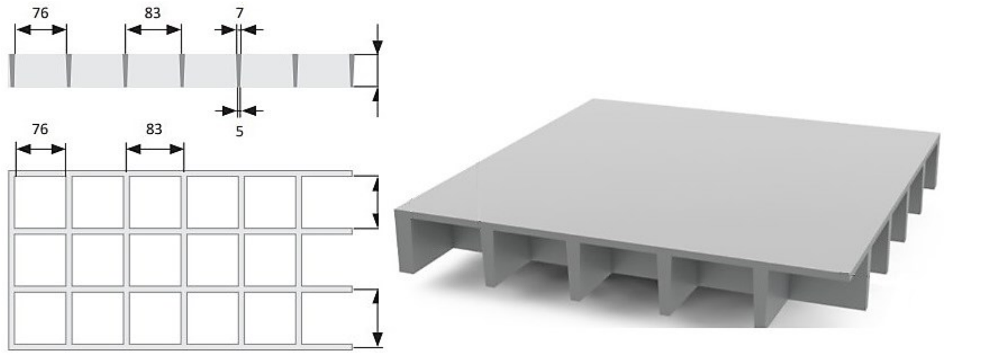

Fig. 15. Composite support grating plate of the body

Using the Finite Element Method, an analytical verification of an open body frame for a delivery vehicle up to 3.5 t was carried out. The following assumptions were made:

vehicle chassis weight (without a body) m_p= 1780 kg - in accordance with the EC certificate of conformity No. e9*2007/46*6109*00

- m_p - vehicle weight (chassis to be developed) - unladen weight (with all fluids, fuel tank 90% full), m_{pk} = 1860 kg, - in accordance with the EC certificate of conformity No. e9 *2007/46*6109*00
- l_c - total length of the vehicle = 5943 mm,
- s_c - total width of the vehicle = 2050 mm,
- l_z - body length = 3505 mm,
- s_z - body width = 2350 mm,
- b - vehicle track width, b = 1790 mm,
- l_o - wheelbase, l_o = 4035 mm,
- h_p - height of the centre of mass of the vehicle (chassis to be developed), h_p = 642 ± 3 mm,
- m_z - body mass, m_z = 1910 kg,
- h_r - height of the upper surface of the construction frame, h_r = 642 ± 3 mm,
- m_{cmax} - maximum allowable total load, m_{cmax} = 3345 ÷ 3500 kg,
- m_{cmax} - maximum allowable load on the front axle, m_{pmax} = 1850 kg,
- m_{cmax} - maximum allowable load on the rear axle, m_{tmax} = 2000 kg,
- n_u - usable load capacity with the driver, n_{u} = 1640 kg,

open body - assumptions for the assessment of the location of characteristic points in the structure are presented in Figure 1:

- l_{zsk} - open body length = 3560 mm,
- s_{zsk} - open body width = 2350 mm,
- s_{zsk} - open body height = 400 mm,
- h_{zsk} - height of the centre of mass of the open body, h_{zsk} = 1063 mm,
- c_{skx} - position of the centre of mass of the open body assembly with a T 108 beam in relation to the transverse axle of the vehicle (X coordinate), *crx1 = 0 mm,*
- c_{sky} - position of the centre of mass of the open body assembly with a T 108 beam in relation to the longitudinal axle of the vehicle (Y coordinate), c_{ry1} = *2746 mm,*
- h_{sk1} - height of the upper edge of the open body, h_{sk} = *1238 mm,*
- m_{sk} - weight of the open body, m_{sk} = 72.8 kg

The analyses were performed in SolidWorks [1] with the use of beam and sheathing elements. Boundary conditions were formulated in the points of fixing the body frame to the vehicle frame. The following load cases were formulated using [8, 29]:

1. body dry weight, tarpaulin weight, wind pressure of 1300 N from the rear of the vehicle.
2. body dry weight, tarpaulin weight and crosswise centrifugal acceleration of inertia of 38 m/s^2,
3. body dry weight, tarpaulin weight and wind pressure on the side surface of the body, with a total value of 2880 N.
4. body dry weight, tarpaulin weight, wind pressure on the side surface of the body with a total value of 2880 N, crosswise centrifugal acceleration of inertia of 38 m/s^2 in the direction of the wind pressure,
5. body dry weight, tarpaulin weight, the force of wind pressure on the side surface of the body with a total value of 2880 N, crosswise centrifugal acceleration of inertia of 38 m/s2 in the direction opposite to the wind pressure,
6. body dry weight, tarpaulin weight, wind pressure on the side surface of the body with a total value of 2880 N, crosswise centrifugal acceleration of inertia of 38 m/s^2 in the direction of the wind pressure, wind pressure from the rear of the vehicle with a value of 1300 N,

7. body dry weight, tarpaulin weight and wind pressure on the side surface of the body, with a total value of 2880 N.

Material used in frame design, analysis and prototype was GRP – glass reinforced polyester. Basics properties shows Table 1.

Table 1. Basic mechanical properties of GRP composite

Parameter		Longitudinally	Transversely
Young modulus	MPa	25000	9000
Poisson number	-	0,23	0,09
density	kg/m3	1900	
Tensile strength (momentary)	MPa	250	30-80
Compression strength (momentary)	MPa	240	30-80
Tensile strength (short time)	MPa	135	25
Compression strength (short time)	MPa	135	20
Tensile strength (long time)	MPa	70	-
Compression strength (long time)	MPa	70	-

The boundary conditions reflected the fixing of the body frame to the steel frame of the vehicle at specific fixing points. The displacement degrees of freedom in these areas were taken from the surface elements. A load of 14 kN, representing the transported load, was distributed on the floor on an area of 800x1200 mm, simulating a pallet load. The resultant loads from the weight of the tarpaulin frame structure and the wind were calculated in separate analyzes as the resultant forces and moments. They were placed at the ends of the side pillars. The diagram of the boundary conditions is shown in the Figure 16.

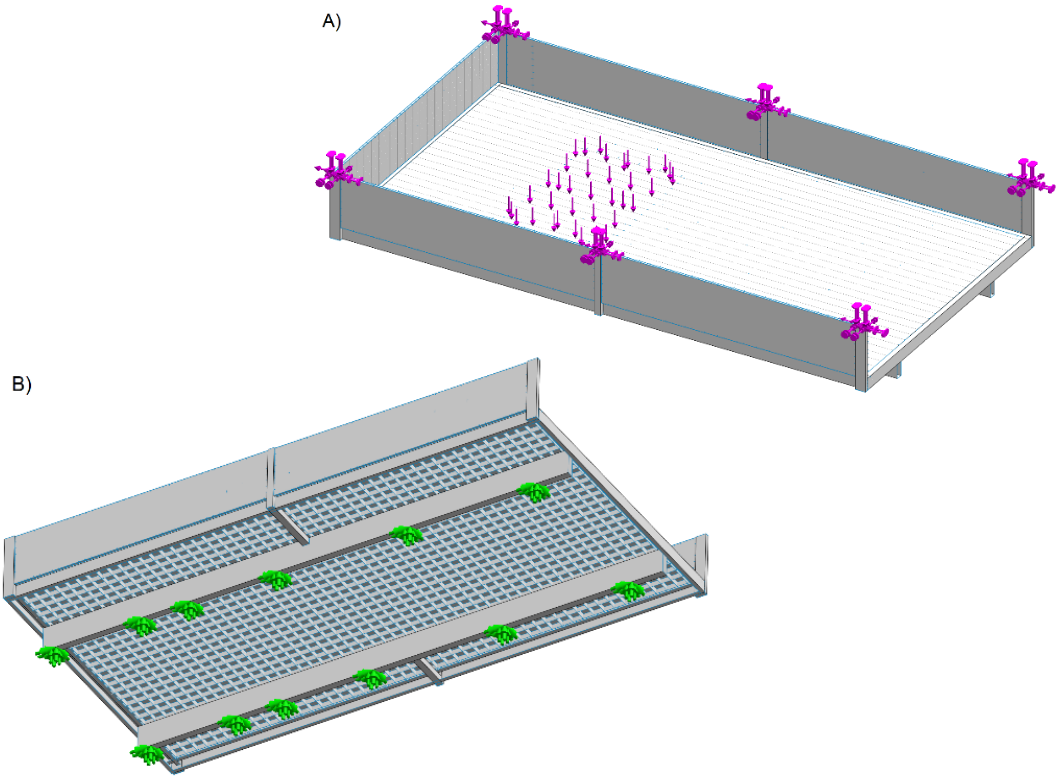

Fig. 16. The diagram of the boundary conditions applied to body frame. A – view from top, B - view from bottom

The results of the analysis of the most severe load case of the structure are presented. In the case of loading with a pallet load, it was possible to obtain a uniform stress distribution without concentration, with maximum the value 25 MPa, not exceeding the material strength limits. The loads from the tarpaulin frame are by their nature concentrated, due to limited space for frame poles. The local value of stresses (96 MPa) at the fixing points of the poles exceeds the long-term strength, but the loads resulting from driving in a curve, wind blows are generally short-term or momentary. For this reason, a higher strength limit should be chosen.

Figures 17 and 18 show the nature of the work of the composite support frame with the open body for the same load variant as in the case of the aluminum alloy body.

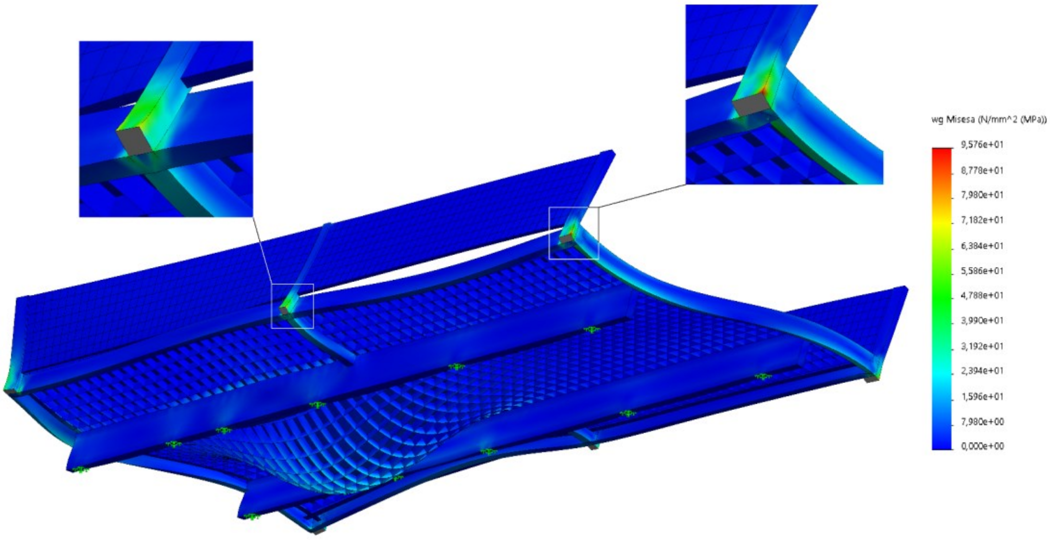

Fig. 17. Map of reduced stresses in the structure of the composite open body under load in the form of a pallet with a weight of 14 kN, dry weight of the structure for the installation of tarpaulin, centrifugal force of inertia and the pressure force of side wind with a direction consistent with the force of inertia of 4800 N

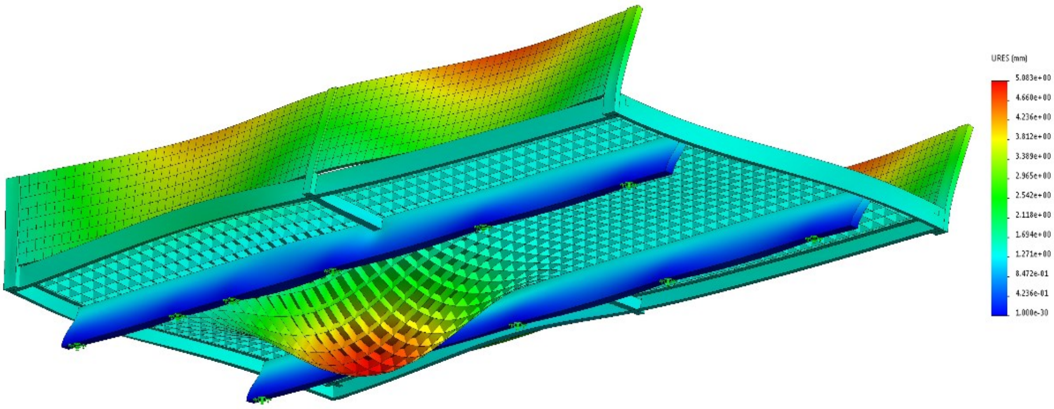

Fig. 18. Map of displacements of the composite structure of the open body under load in the form of a pallet with a weight of 14.5 kN, dry weight of the structure for the installation of tarpaulin, centrifugal force of inertia and the pressure force of side wind with a direction consistent with the force of inertia of 4800 N

CONCLUSIONS

Issues related to designing support frames and bodies for electric delivery vehicles (eVans) are the topic discussed by engineers around the world. Currently, no attempts to make/produce vehicle bodies based on fibre composites on larger scale, apart from a narrow segment of luxury or sport cars, are being reported in the source literature, trade periodicals and on manufacturers' websites.

The authors of the article designed and constructed a prototype polymer body for a delivery vehicle. They conducted detailed numerical analyses on the prototype and preliminary experimental tests.

The stability coefficient of the body frame for the installation of tarpaulin was determined and the loads transferred by the system to the structural elements of the open platform and the support frame of the body were determined. The phenomena occurring in the structure subjected to static loads with the structure's dry weight, tarpaulin weight, external operational loads and variants of the above-mentioned impacts were verified.

It was found that for most cases the main factor influencing the level of maximum stresses in the support frame and body is the weight of the transported cargo. In the case of the solution using composite gratings, the local influence of cargo placement was limited, which made it possible to obtain a uniform tension of the entire structure of the body. In the original development solution, the number of components was reduced, which will translate into a reduced cost of the structure and production time.

The estimated stiffness in the case of the composite body is (2882 N/mm). The designed solution is characterized by a high safety factor {alu-composite relation}. Stress and displacement levels and the nature of the structure work for the materials: aluminium and composite are comparable.

The direction of using composite materials in vehicle structures opens up new possibilities in the design and adaptation of delivery vehicles, especially electric ones. The demonstrated possibility of reducing the weight of the structure through the use of composite materials allows to increase load capacity or compensate for the increase in weight resulting from the use of electric drive systems. For comparable vehicle operating conditions, it will be possible to reduce energy consumption per unit of distance.

The obtained results clearly confirmed the correctness of the formulated thesis about the possibility of designing bodies made of structural plastics dedicated to electric vehicles.

Future plans include an evaluation of the possibility of modifying the structure frame and the vehicle load-bearing frame in order to accommodate the modular power cells of the electric drive train within the load-bearing structure.

WYBRANE ZAGADNIENIA Z ANALIZY KOMPOZYTOWYCH NADWOZI POJAZDÓW

Problematyka projektowania ram nośnych i zabudów pojazdów dostawczych elektrycznych typu eVan jest przedmiotem opracowań dyskusji środowiska inżynierskiego na całym świecie. Procesy projektowania bazują na klasycznych modelach rozwiązań wykorzystujących profile ze stali konstrukcyjnej. Kierunki rozwoju obejmują wytwarzanie ram wysoko wytężonych ze stali o podwyższonych parametrach wytrzymałościowych. Autorzy artykułu zaprojektowani i wykonali polimerową prototypową zabudowę pojazdu dostawczego. Przeprowadzili szczegółowe analizy numeryczne na prototypie oraz wstępne badania doświadczalne. Uzyskane wyniki jednoznacznie potwierdziły słuszność sformułowanej tezy o możliwości zaprojektowania zabudów dedykowanych pojazdom elektrycznym z tworzyw konstrukcyjnych.

Słowa kluczowe: eVan, materiały kompozytowe, pojazd dostawczy, rama nośna pojazdu, zabudowa transportowa

REFERENCES

[1] Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (Framework Directive).

[2] Ważyńska-Fiok K., Jaźwiński J. (1990). *Niezawodność systemów technicznych*, PWN.

[3] Szabo F.J. (2018). Optimization of springs applied in vehicle suspension structure. In: Jármai, K, Bolló, B (eds) *Vehicle and automotive engineering*. Cham: Springer, 585–596.

[4] Beer F., DeWolf J., Johnston E.R., et al. (2014). Mechanics of materials. New York: McGraw-Hill Education.

[5] Editorial Board of the Automotive Engineering Manual (2001) Automotive engineering manual (for design). Beijing, China: China Communications Press.

[6] CEB-FIP Model Code 1990, (1991). Committee Euro-International du Beton, Bulletin d'information, No. 195, 196.

[7] Orzełowski S., (2009). Budowa podwozi i nadwozi samochodowych.

[8] Reimpell J., Betzler W.J., (2001). *Podwozia samochodów. Podstawy konstrukcji*, WKŁ.

[9] Reński A. (2004). *Budowa samochodów: układy hamulcowe i kierownicze oraz zawieszenia*, WKŁ.

[10] Zieliński A. (2008). *Konstrukcja nadwozi samochodów osobowych i pochodnych*, WKŁ.
[11] Granovskii M., Dincer I., Rosen, M.A., (2006). Economic and environmental comparison of conventional, hybrid, electric and hydrogen fuel cell vehicles, *Journal of Power Sources*, 159(2), 1186–1193.
[12] Khanse K.R., Shekhar P.P. (2013). Test set-up of BIW (Body in White) stiffness measurements, *SAE technical paper*, 2013-01-1439.
[13] Informacje handlowe dotyczące wyrobów firmy AL-KO Technology Polska Sp. z o.o. 2021.
[14] Informacje handlowe dotyczące pojazdów Fiat Ducato do zabudowy 2021.
[15] Zehsaz M., Sadeghi M.H., Ettefagh M.M., et al. (2015). Fatigue strength of a chassis of a semi-heavy truck under dynamic loads due to real road roughness, *Trans FAMENA*, 38(4): 89–105.
[16] Kim Y., Yang J.M., Cho T. et al. (2019). Noncontact bending and torsional stiffness estimation model for automobile frames based on 3D displacements, *IEEE Sens Journal*, 19(17), 7707–7717.
[17] Lee E. M., Shim D.S., Son J. Y. et al. (2016). Study on design of progressive dies for manufacture of automobile structural member using DP980 advanced high strength steel, *Journal Mech Sci Technol*, 30(2), 853–864.
[18] Wang, X. C., Lu Q. et al. (2019). Numerical analysis on aerodynamic performance of different automobile body shape, IOP Conf Ser Earth Environ Sci, 242(3): 032027.
[19] Hongshen Z., Gan H., Dali Y. (2019). Numerical modeling for the frame structure of light van-type electric truck, *Sage Journal* 5/2020.
[20] Wang X., Xu, W, Huang et al. (2012). Simulation of the vertical bending fatigue test of a five-link rear axle housing, *Int Journal Automot Technol*, 13(6), 923–932.
[21] Zhang M., Ji X., Li L. (2016). A research on fatigue life of front axle beam for heavy-duty truck, *Adv Eng Softw*, 91, 63–68.
[22] Duan L., Sun G., Cui J., et al (2019). Crashworthiness design of vehicle structure with tailor rolled blank, *Struct Multidiscip Optim*, 53(2), 321–338.
[23] Zuo W., Yu J., Saitou K. (2016). Stress sensitivity analysis and optimization of automobile body frame consisting of rectangular tubes. *Int Journal Automot Technol*, 17(5), 843–851.
[24] Aghav H.L., Walame M.V. (2016). Stress analysis and fatigue analysis of front axle of heavy-duty truck using ANSYS Ncode design life for different loading cases, *Journal Eng Res Appl*, 6(6), 78–82.
[25] Jenefeldt F. (2008). Investigating the effects of strengthening the crossbeam in frontal car-to-car impacts, *Int Journal Crashworthiness*, 13(1), 1–8.
[26] Ma Y., Li Y. (2011). Fatigue life analysis of the van body frame based on ANSYS, AIMSEC.
[27] Zhou C., Zhao L. (2012). Analytical calculation theory of elastic mechanics of vehicle suspension, Mechanical Industry Press.
[28] Ma X., Sheng Y. (2004). Finite element analysis and optimization of frame stiffness and modal, Bus Technol Res, 26(4), 8–11.
[29] New Fiat Ducato (2016). Converters' and Upfitters' Manual.