OPTIMIZATION OF FASTENING CONSTRUCTION
FOR THE PORTABLE TANKS

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Abstract: *The aim of the research presented in this article is optimization of support/fastening for the portable tank which holds liquified gases. Two criteria were considered: ensuring a minimal construction mass and a minimal production costs while strength conditions are fully met for subject of study.*

Keywords: fastening construction, portable tanks, finite element method, MPGM

1. Introduction

Fastening construction which is important piece of improvement of transport process, are also used to capture the leaks from tanks. They allow to reduce negative influence of substances that can threaten the natural environment and even workers. It is important to reduce the risk of losing transported materials. Such a functionality does not take place in case of pallets prepared for barrels with liquid gases, because of high internal pressure. The most important property (Pawłowski, 2009) that describe fastening construction is maximum load that has to be maintained. The ones (pallets) used to place portable tank apart from requirement of stiffness have to go through a series of durability trials which evaluates its value under static load. Stresses that appears as effect of these test actions may lead to deformations of its original shape in points where tests are most intensive. Finally, forces that affect the construction changes positions of its parts and their deformation (Ashby, 2007).

2. Design and optimization assumptions

Optimization of fastening construction of portable tank for liquid gas considered simultaneously two criteria: ensure a minimal weight and minimal cost of implementation, and at the same time fulfill strength criterion included in relevant standards. Research takes following project variables: length, width and height of construction, sheet thickness, thickness of profiles. Research method and numerical calculations used weighted sum method (Jureczko, 2013 and Kim, 2005).

Strength conditions that applies to fastening constructions are included in EN 14208 "Transportable gas cylinders – specification for welded gas drums up to 3000 litre capacity for the transport of gases - Design and construction" and its equivalent approved by European Committee for Standardisation (CEN). According to them "portable tanks and their fastenings shall, under the maximum permissible load, be capable of absorbing the static force directed vertically downwards, which values is twice the MPGM (where MPGM means the sum of the tare mass of the portable tank and the heaviest load authorized for carriage) multiplied by the acceleration due to gravity. Under this force, the safety factor for steels having a clearly defined yield point should be equals 1.5 in relation to the guaranteed yield strength' (ADR 6.7.3.2.10, 2017)."

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Defining the cost of implementation of fastening construction, the both: labor and material costs were taken into account (e.g. welder work cost).

Taking into account the imposed conditions, the pallet construction is shown in Fig. 1a.
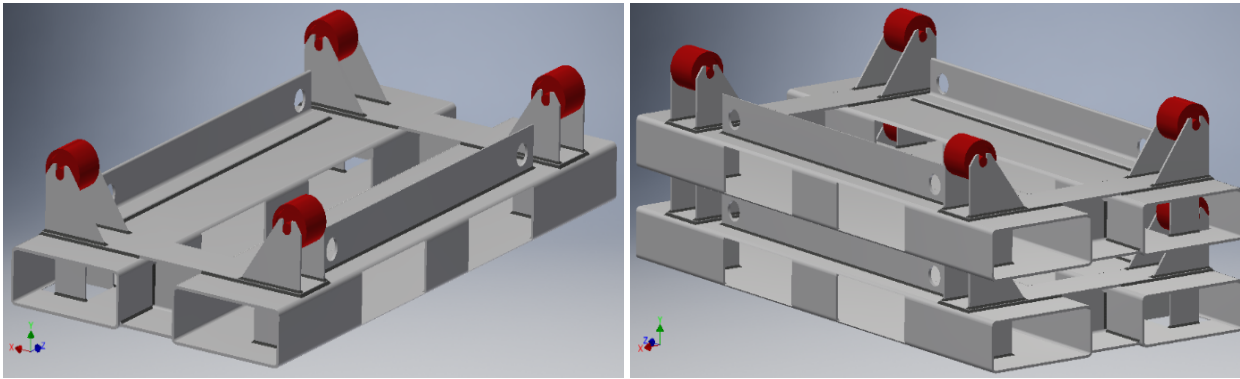

Fig. 1: CAD model of the fastening construction: a) single, b) multiple.

Palette was designed as inseparable construction made of profiles. Project include possibility of safe stacking of multiple platforms through use of grooves on the bottom of palette which blocks rollers and prevent spontaneous movements relative to each other. Block rollers have dimensions: diameter 85 mm, width: 80 mm, with polyurethane tread, where the shield is made of steel. Load capacity of single roll: 610 kg. Rolls are placed in every of four support points of tank. Uneven brackets are handles for tension belts, additionally strengthening and stiffening construction increasing also its weight. Fig. 1b presents situation when platforms are placed one on the top of other, where platform is stabilized on the edge of angles, rolls hide in prepared pockets stabilizing whole system. Inside profiles were introduced shields, which protects rolls during removal of pallets from the stack through the shorter edge. This construction allows designed palettes to be transported by the forklift with smaller fork spacing. Pockets on the long side does not introduce any limitations in this aspect.

It was assumed that platform will be strained with standard tanks, with outer diameter of 800 or 900 mm. The maximum weight of the tank is 2400 kg.

Mechanical properties of construction material applied in Autodesk Inventor are presented in Tab. 1. It is Alloy Steel S235JR+N.

Tab. 1: Properties of structural low-alloy steel S235JR+N.

Young's modulus	210 GPa
Poisson's ratio	0.3
Kirchhoff module	80000 MPa
Density	7.85 g/cm^3
Plastic range R_e	235 MPa
Tensile strength	360 MPa

3. Numerical model

FEM calculations were carried out in statistical analysis model. Coefficient of welded joints has been applied as value 1. Basement of model has been bond in stationary manner. For simulation purposes the value of gravity was assumed as 9810 mm/s^2. Gravity is marked with red arrow in Fig 2a. A total of 180 geometric contacts bonding the elements of the model were indicated on the structure. All joins were made as fillet welds with a width of 4 mm. The total length of all fillet welds in the construction was 875 mm, no discontinuities were used. The value of loading force is 50000 N. It is transferred to construction through 8 points, which are roller supports, which is base for rolls that support stored tank. Because of its big dimensions (diameter of tank − 900 mm − is over 50% larger than distance between wheels of pallet) transferred load works in the direction that only slightly deviates from y-axis. Therefore, for simplicity load value is focused along this axis. Load that comes from tank was presented as yellow axes in Fig 2a. For creation of FEM elements mesh mean value of single element was set as 0.035. The

value of gradation coefficient was set to 1.5, and none of the model angles exceed 60 degree. These parameters produced model grid from 614 236 elements and 338 873 nodes. Construct with mesh grid is shown in Fig 2b.
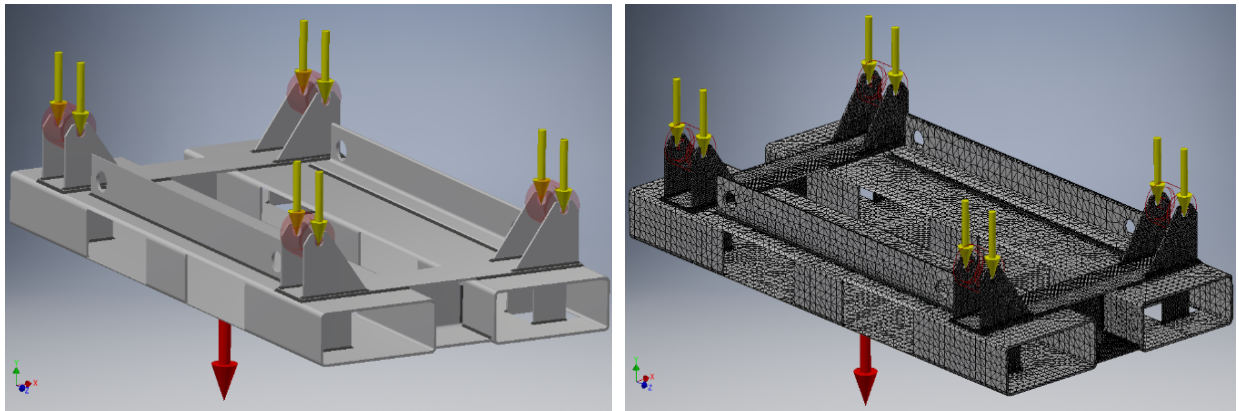

Fig. 2: a) CAD model of the fastening construction with marked loads, b) generated mesh model.

4. Result analysis

Analyzing the pallet, design takes into account both the palette itself, and the shaft on which the roll is suspended on a pallet holding tank. For simulation purposes, a roller was modelled with uniform diameter 20 mm along whole 100 mm length. Fig. 3 presents obtained stress maps respectively for whole construction (a) and the element most exposed to destruction i.e. roller (b).
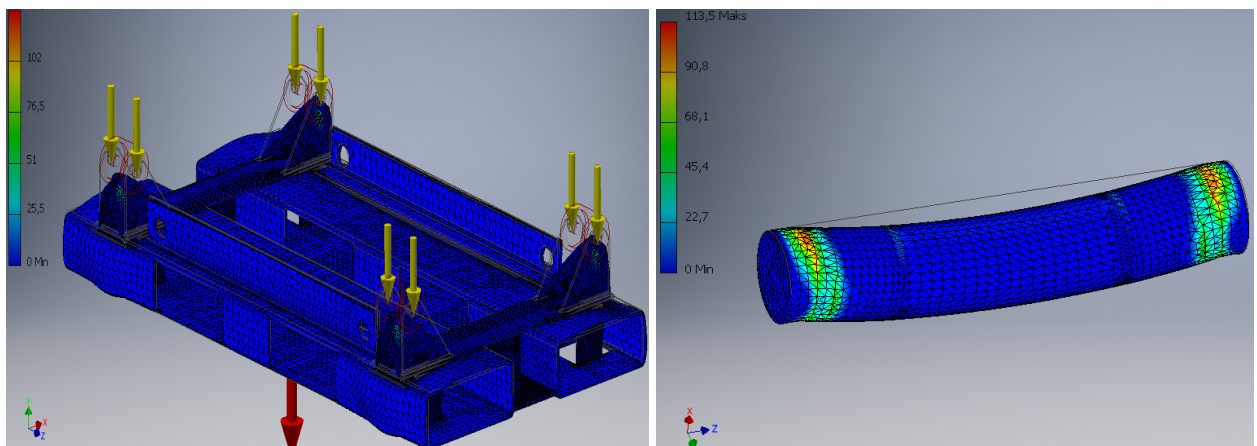

Fig. 3: Map of the reduced stress for: a) the fastening construction, b) roller.

Tab 2 presents results of numerical strength analysis.

Taking into account the below values, it is clear that none of the occurring stresses exceed the yield criterion of structural low – alloy steel used. Using equation:

$$\frac{R_e}{\sigma_{red}} > 1.5 \qquad (1)$$

it was checked whether the condition regarding the safety factor was met.

The highest obtained value of reduced stresses was 127.548 MPa. In relation to it, the apparent yield strength of the material used has a value of 235 MPa and has a safety factor of 1.84. Also, value of reduced stress 117,742 MPa obtained for the roller and compared to yield criterion of applied material showed safety value of 1.85. Thus, the optimized design meets the previously described requirement of ADR 6.7.3.2 2017.

Tab. 2: Results of numerical strength analysis.

	the fastening construction		roller	
	minimum	maximum	minimum	maximum
normal stresses σ_x	-53.487 MPa	34.032 MPa	-148.516 MPa	149.228 MPa
normal stresses σ_y	-126.493 MPa	27.402 MPa	-80.653 MPa	83.962 MPa
normal stresses σ_z	-14.764 MPa	15.151 MPa	-131.336 MPa	128.314 MPa
shear stress τ_{xy}	-29.964 MPa	32.0326 MPa	-36.072 MPa	34.478 MPa
shear stress τ_{xz}	-15.964 MPa	15.846 MPa	-48.303 MPa	47.982 MPa
shear stress τ_{yz}	-20.887 MPa	19.2198 MPa	-22.904 MPa	23.117 MPa
reduced stress σ_{red}	0.00000017 MPa	127.548 MPa	0.000831123 MPa	117.742 MPa
displacement along X axis	-0.026539 mm	0.026397 mm	-0.013575 mm	0.000196 mm
displacement along Y axis	-0.024139 mm	0.006899 mm	-0.000439 mm	0.000438 mm
displacement along Z axis	-0.030744 mm	0.030778 mm	-0.005191 mm	0.005192 mm

5.   Conclusions

As a result of the bi-selective optimization, a pallet with a weight of 77 kg and the following dimensions was obtained: length 1200 mm, width 625 mm, height 250 mm. The thickness of sheets and profiles used in the pallet construction was 5 mm. This dimension takes into account the requirements for the use of forklifts, as described in EN 14208. The cost of its production was estimated at PLN 1550. However, due to the large number of welded joints and cut-outs, which reduced the mass of the entire structure, the pallet's time of manufacture was estimated at approximately 7.5 hours.

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