

An Analysis of Selected Container Structures with Built-In Multi-Layer Composite Sheets with the Use of FEM

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Received July 15.2014; accepted July 20.2014

Summary. In this paper presents 3D digital models of selected variants of container structures. A rigidity analysis of objects with built-in multi-layer composite sheets has been carried out and it has been compared with calculation results for classical structures. Numerical calculations have been performed with the use the Finite Element Method. The results obtained may be widely used in container structures designed for farming, building engineering and transportation.

Key words: computer aided design, finite element method, multi-layer composite sheets, polyoptymalization.

panels, on the other hand they increase the rigidity of the framework as well as improve its endurance parameters.

A multi-layer composite sheet consists of three layers:

- external layer – a 1-millimeter steel sheet,
- internal layer – a 50-millimeter composite material,
- there is an additional face layer made of plastic.

INTRODUCTION

Large-size multi-layer composite sheets are made using the technology of in vacuum presses. Composite elements are used, among others, for building self-bearing mixed-use container structures. Composite elements of walls are used, among others, in farming for building freezers and utility rooms.

Composite sheets are glued in vacuum presses. The working principle of the press is based on the effect of negative pressure (vacuum) generated between a properly formed surface of the work table and a rubber membrane covering the elements of sheets to be attached with adhesive. The pressure force of the elements of a multi-layer sheet depends on the value of generated vacuum. The effect of negative pressure is obtained using a correctly selected vacuum pump which sucks off the air from the space between the work table and the rubber membrane [8].

Classical container structures are made using the technology of welding steel sections which form a framework the walls of which are made of metal sheets, and insulating materials do not increase the rigidity of the entire structure. A modification of a classical construction of containers involves attaching multi-layer composite sheets into a framework using adhesive. On the one hand they form external



Fig. 1. Composite sheet

This paper presents issues related to digital modeling and endurance calculations of a framework of a classical container as well as its modification with composite sheets attached with adhesive.

In the next stages of this work endurance and rigidity calculations of selected variants of the container's structures using CAD systems (the Finite Element Method) were carried out. This resulted in building a container framework with composite sheets attached with adhesive as well as verification of numerical calculations at a testing station [2, 3, 4, 5, 12, 13].

DIGITAL MODELS OF A FRAMED CONTAINER STRUCTURE AND ITS VERSION WITH COMPOSITE SHEETS ATTACHED WITH ADHESIVE

Digital models of different variants of the structure were performed using Inventor v13 system made by Autodesk. During the designing process, all geometrical, material and dynamic features both in their quantitative and qualitative forms were attributed to the said structures [18, 19, 20]. This allowed us to conduct simulation calculations using FEM. The FEM module is included in Inventor software and allows the user to perform numerical calculations directly on the object being modeled [7, 9, 10, 15, 16]. In Figure 2 solid models of selected variants of container structures are presented (framed and with composite sheets).

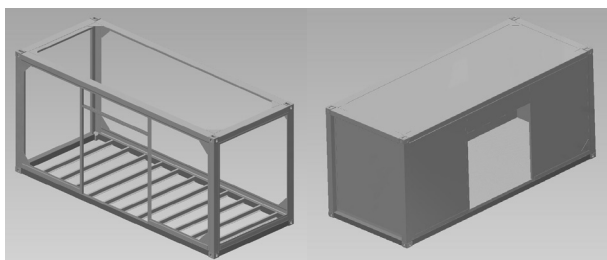


Fig. 2. Digital models of selected variants of container structures

RIGIDITY CALCULATIONS OF CONTAINER STRUCTURES

A digital displacement map of container models exposed to both their own and external load has been determined using FEM (the Finite Element Method) [14, 17, 21, 22]. An important stage of the work was to create an interaction model of a set of components, yet taking into consideration contact stress between two deformable objects. This task was performed by means of modeling the contact area using the "surface-to-surface" method as follows [21]:

- creating a geometrical model of an object,
- selecting properties of materials,
- determining the contact area,
- defining the type of contact,
- creating a network of finite elements,
- introducing boundary conditions,
- carrying out calculations,
- analyzing the calculation results.

The following construction materials were used in digital models of container structures. The framework of the container was made of steel sections, multi-layer sheets were made in the technology of gluing and consist of an exter-

nal layer of steel sheets and an internal layer of composite Styrofoam.

Four load variants were taken into consideration while conducting calculations, which complies with the research method applied at certification laboratories. Forces in particular variants (except the dead load) were applied at upper corners of the container. The table below presents values of the applied forces:

Table 1. Values of forces applied

Load case	Value of force
Vertical force	318 000N
Transverse force	75 000N
Longitudinal force	75 000N
Dead load	-----

Fig. 3. presents three models of load cases of container structures. The method and location of forces applied complies with the actual research procedure used at measurement stations.

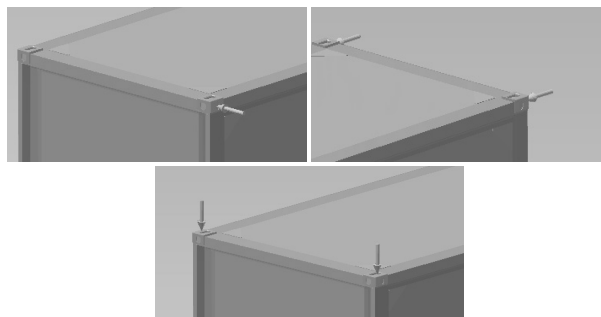


Fig. 3. Methods of applying forces at the measurement station.

In order to perform a FEM analysis degrees of freedom in the digital model of the container were eliminated using braces. Four "permanent" braces were used (elimination of six degrees of freedom); they were attached to lower surfaces at the basis of corner columns, according to the below presented figure.



Fig. 4. Stability brace in a digital model of the container

In a digital model of a container with composite sheets 782 contact pairs were generated between the framework and sheets.

While performing an analysis of this set (the container with composite sheets) models of 46 elements, being thin solids, were simplified. This allowed us to carry out calculations for a case in which a given structure includes elements of considerably differentiated dimensions [10].

Then the area of analysis was discretized as a result of which a network of finite elements was generated.

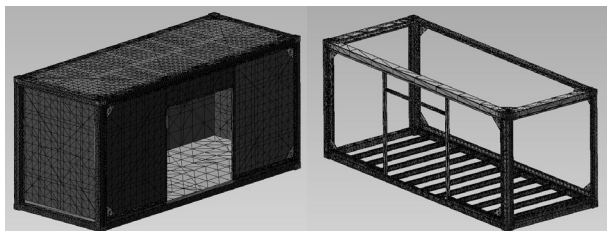


Fig. 5. Partitioning of container models into finite elements

With the use of the “solver” function of FEM digital displacement maps for particular container versions were generated. Fig. 6 presents displacements of the structure of the container without composite sheets exposed to vertical forces applied to upper corners of the framework.

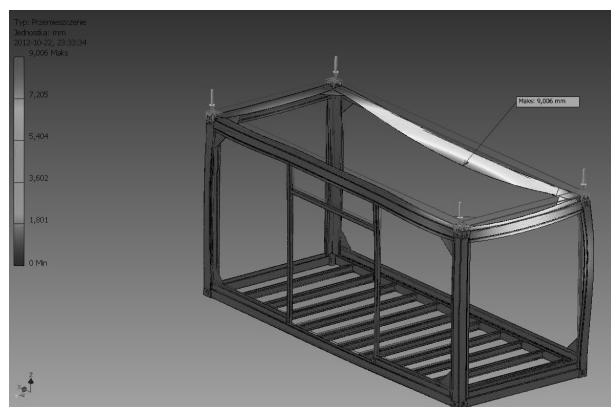


Fig. 6. Deformation map of a container without composite sheets

For comparison Fig. 7 presents a digital displacement map of a container with composite sheets attached with adhesive.

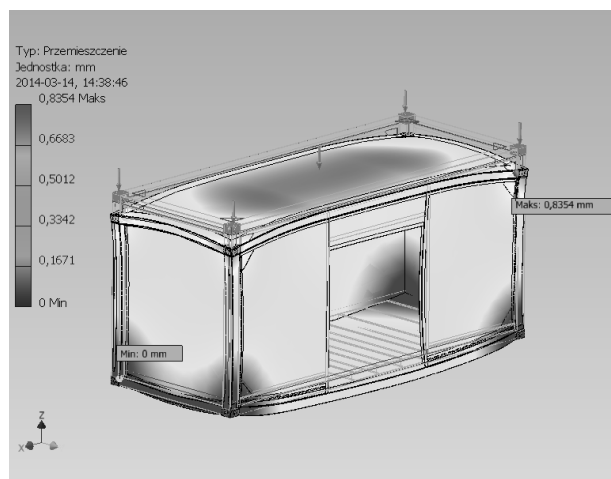


Fig. 7. Deformation map of a container with composite sheets

Table 2. Representation of obtained calculation results:

Load type	Container without composite sheets	Container with composite sheets
Vertical force	9,01 mm	0,85 mm
Longitudinal force	63,00 mm	0,44 mm
Transverse force	63,92 mm	0,60 mm
Dead load	5,58 mm	0,08 mm

The results of rigidity calculations indicate that the deformation of a container structure with composite sheets is more than tenfold smaller than in the case of a structure whose only bearing element is its framework. Multi-layer composite sheets used as container walls have an additional function and they increase to a considerable extent the rigidity of the structure under examination. The suggested solution proves to be effective in the case of high container storage, e.g. on cargo ferries or warehouses where the use of space is particularly important and containers are stacked up.

VERIFICATION OF CALCULATION RESULTS OBTAINED

On the basis of the said digital model a prototype container was built by KONTENER Production of Building Elements LLC in Płock. Experimental studies at a research station involving the application of standardized values of forces to an actual structure were conducted. Empirical studies confirmed the results of numerical calculations [11]. The structure fulfilled the assumed criteria for rigidity and endurance. The deformation of the structure of the container with composite sheets did not exceed allowable values.

CONCLUSIONS

The calculation results obtained were presented in the form of numerical maps and tabular representations. The analysis of theoretical calculations demonstrated compliance with the results obtained by means of empirical studies.

The use of CAD systems and FEM calculations in the case of problems discussed in this paper provide measurable advantages including:

- a considerable shortening of the time needed for studies owing to numerical analysis of numerous variants of container structures,
- conducting credible research using computer systems as early as at the designing stage,
- a possibility of designing container structures consisting only of multi-layer sheets after a prior numerical and experimental verification, without a steel framework, which will considerably reduce their costs and weight.

The research methodology suggested in this paper has been used in practice in order to perform contracts for the engineering industry, farming, civil engineering as well as defense industry.

REFERENCES

1. **Bogucki M., 2009:** Optymalizacja doświadczalna. Wariant jednokryterialny, MOTROL Motorization and power industry of agriculture, volume 13, Komisja Motoryzacji i Energetyki Rolnictwa PAN Oddział w Lublinie, 11c, 22-30.
2. **Branowski B., 1998:** Wprowadzenie do projektowania, PWN.
3. **Chlebus E., 2000:** Techniki komputerowe CAx w inżynierii produkcji, WNT.
4. **Dietrych J., 1978:** System i konstrukcja, WNT.
5. **Encarnacao J.L., Lindner R., Schlechtendahl E.G., 2000:** Computer Aided Design, Springer-Verlag.
6. **Gendarz P., 1998:** Aplikacje programów graficznych w uporządkowanych rodzinach konstrukcji, Wydawnictwo Politechniki Śląskiej, Gliwice.
7. **Jaskulski A., 2009:** Autodesk Inventor 2009PL/2009+ metodyka projektowania, PWN.
8. **Jakliński J., Lodwik D., Malesa W., Wiktorski Z., 2012:** The test stand calculations of the research station of sub-atmospheric pressure press with implementation of the finite element method, TEKA Kom. Mot. I Eng. Roln. OL PAN, Vol 12. No. 2. 81-86.
9. **Król K., 2006:** Metoda elementów skończonych w obliczeniach konstrukcji, Politechnika Radomska, Wydawnictwo.
10. **Kruszewski J., Gawroński W., Wittbrodt E., Najbar F., Grabowski S., 1975:** Metoda sztywnych elementów skończonych, Arkady.
11. **Maksimow V., Galgash R., Synytsya L., 2010:** Information and organizational-economic aspects of innovative development management of regional enterprises, TEKA Kom. Mot. I Eng. Roln. OL PAN, 10D, 184-189.
12. **Niezdodziński M.E., Niezdodziński T., 1996:** Wzory, wykresy i tablice wytrzymałościowe, WNT.
13. **Osiński Z., Wróbel J., 1995:** Teoria konstrukcji, PWN,
14. **Rakowski G., Kacprzyk Z., 2005:** Metoda elementów skończonych w mechanice konstrukcji, OWPW.
15. **Rohatyński R., Miller D., 1994:** Problemy metodologii i komputerowego wspomaganie projektowania technicznego, tom 1, Wydawnictwo Politechniki Wrocławskiej.
16. **Sydor M., 2009,** Wprowadzenie do CAD. Podstawy komputerowo wspomaganego projektowania, PWN.
17. **Szmelter J., Dacko M., Dobrociński S., Wieczorek M., 1979:** Metoda elementów skończonych w statyce konstrukcji. Przykłady obliczeń, Arkady.
18. **Szymczak C., 1998:** Elementy teorii projektowania, PWN.
19. **Tarnowski W., 1997:** Podstawy projektowania technicznego, WNT.
20. **Wróbel J., 2004:** Technika komputerowa dla mechaników, OWPW.
21. **Zagrajek T., Krzesiński G., Marek P. 2006:** Metoda elementów skończonych w mechanice konstrukcji. Ćwiczenia z zastosowaniem systemu ANSYS, OWPW.
22. **Zienkiewicz O.C., 1972:** Metoda elementów skończonych, Arkady.

ANALIZA Z ZASTOSOWANIEM MES
WYBRANYCH KONSTRUKCJI KONTENEROWYCH
Z WBUDOWANYMI WIELOWARSTWOWYMI
PŁYTAMI KOMPOZYTOWYMI

Streszczenie. W pracy przedstawiono modele cyfrowe 3D wybranych wariantów konstrukcji kontenerów. Dokonano analizy sztywnościowej obiektów z wklejonymi wielowarstwowymi płytami kompozytowymi i porównano z wynikami obliczeń dla konstrukcji klasycznych. Obliczenia numeryczne zrealizowano z zastosowaniem metody elementów skończonych. Uzyskane wyniki obliczeń można wykorzystać w konstrukcji obiektów kontenerowych przeznaczonych dla rolnictwa, budownictwa oraz szeroko rozumianego transportu.

Słowa kluczowe: komputerowo wspomagane projektowanie, metoda elementów skończonych, wielowarstwowe płyty kompozytowe, polioptymalizacja.