COMBINED HIGH-PRESSURE VESSEL FOR FUEL GAS STORAGE

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Introduction

The use of unconventional motor fuels - natural gas, biofuels, hydrogen, etc. have always been under the scope of research due to the limited availability of most of the available oil sources.

Every country contesting for the commercial fuel market is interested in the technology of composite vessel design. Therefore, it is urgent to create new efficient designs of gas pressure vessels and reliable methods for their calculation. The volume of fuel supplied delivering gas to high-pressure vessels is limited by the vehicle's load capacity. The use of lighter metal composite cylinders will increase the volume of transported gas and consequently reduce the cost of transporting gas.

Methods

- solution for geometrically nonlinear contact problems is developed on the base of a mixed high order and layer-wise theory of multilayer plates and shells under sticking contact at one part of the interfacial boundary and areas of delamination with sliding contact occur on the other;

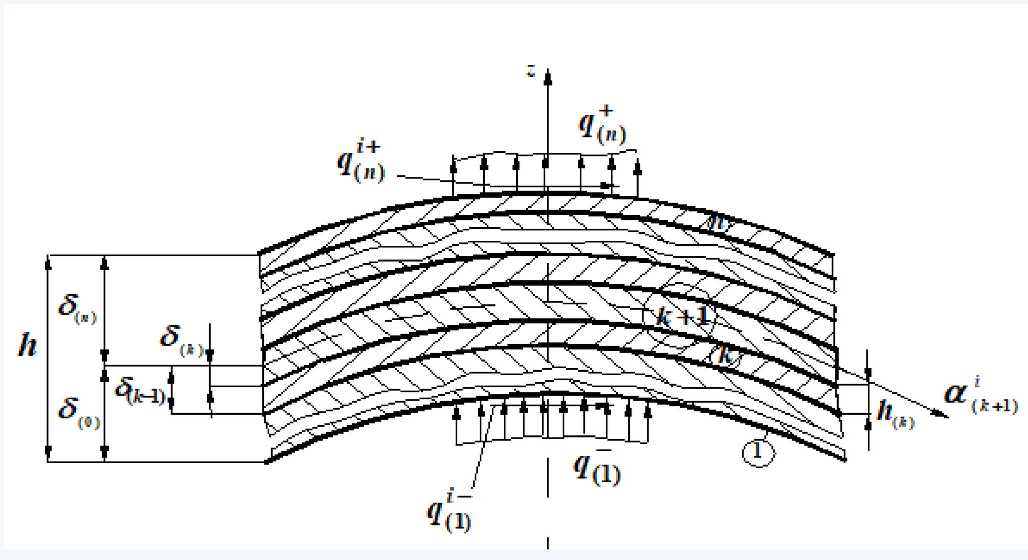

Fig .1 Computational model of multilayered shell

- the numerical results obtained on the basis of three variants of the computational models of multilayered shells and plates was experimentally verified;

Fig.2 Experimental assemblies

- the method of estimation of structural strength and load-carrying capacity of the new design of the combined high-pressure vessel is developed.

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Results

The analysis of the theoretical and experimental results has shown the adequacy for a computational model of the two-layered plates and shells of a variant, which allows the elastic sliding along contacted layers boundaries. The error in the theoretical plate deflection in the centre of the plate with the experimental data was less than 3%. The geometrically non-linear terms improve the accuracy of the radial stresses σ_r.

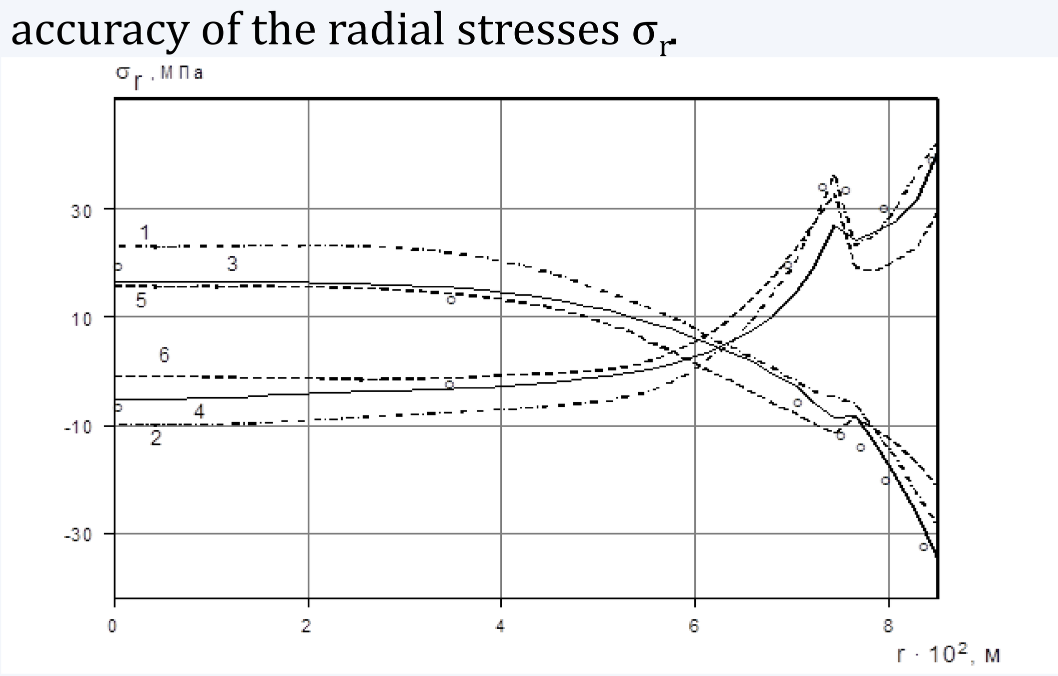

Fig.3 Radial stresses along radius on top and bottom of plate with round defect (1,2 –II model; 2,3 – I model; 5,6 – II model FEM; º - experiment)

The combined high-pressure vessel contains an inner protective plastic shell and a cylindrical glass fiber reinforced plastic (GFRP) shell. Forming details of spherical bottoms are located on the end sections of the supporting GFRP shell. In addition, the GFRP shell on the outside is protected by a metal sheath consisting of a circular cylindrical shell and spherical bottoms in contact with the spherical bottoms of the GFRP shell.

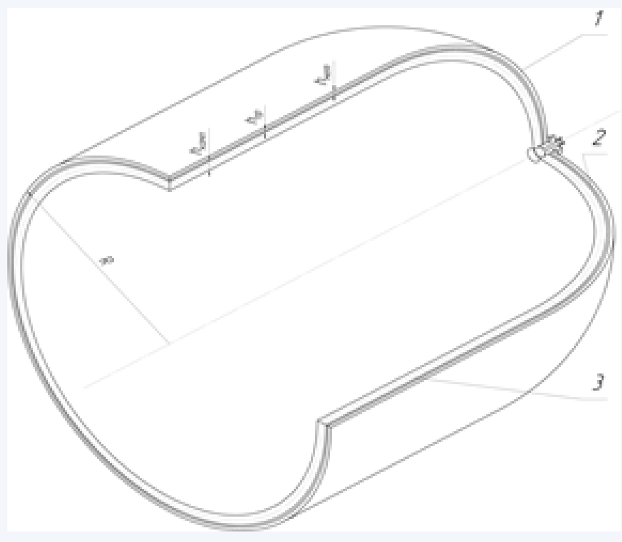

Fig.4 Computational model of combined high-pressure vessel

Table 1 High-pressure vessels' constructions

№	Length of cylindrical part, m	The outer radius of the cylinder and sphere R, m	Glass fibre reinforced plastic shell thickness h_C, m	The thickness of the gap h_3, m	The thickness of the protective metal shell of the cylinder h_M, m	Design weight, kg
1	2.163	0.188	0.0275	0	0	160
2	2.163	0.188	0.033	0	0	188
3	0.886	0.257	0.041	0	0	175
4	2.163	0.188	0.02	0.002	0.004	154.5
5	2.163	0.188	0.02	0.004	0.004	160
6	0.886	0.257	0.035	0.004	0.004	180
7	0.886	0.257	0.03	0.004	0.006	165

Table 2 Ultimate pressures for designs

№	Ultimate pressure of matrix p_1, MPa	Ultimate pressure of fibres p_2, MPa	Ultimate pressure of the metal shell according to strength of intensity p_{III}, MPa	Ultimate pressure of the metal shell according to von Mises strength p_{IV}, MPa
1	27,90±0,05	58,32±0,005	–	–
2	29,45±0,05	61,93±0,005	–	–
3	28,60±0,05	64,03±0,005	–	–
4	28,10±0,05	58,70±0,005	42,50±0,05	52,00±0,05
5	27,80±0,05	55,36±0,005	54,80±0,05	58,00±0,05
6	29,10±0,05	65,85±0,005	58,05±0,05	62,50±0,05
7	28,60±0,05	62,07±0,005	58,65±0,05	62,55±0,05

Discussion

- The inner GFRP shell practically transfers most of the loads on the more rigid outer metal shell.
- Varying the GFRP shell rigidity and soft filler thickness between the inner part and the metal shell makes it possible to achieve conditions of equal strength of the materials involved. The longitudinal deformation of the GFRP shell is eliminated by the metal protective shell rigid enough along the cylinder axis. Thus, the proposed variant of the vessel design can significantly reduce the amount of circular and longitudinal stresses compared to its analogues, having a traditional cylindrical shape.
- A new method of calculating its structural strength is proposed in order to evaluate the load-carrying capacity of the combined high-pressure vessel, using a stepped algorithm and a modified tensor-polynomial strength criterion, which includes transverse shear stresses and transverse normal stresses, it is easy to find the moment of matrix failure and the breaking down of static and kinematic boundary conditions of contact between the layers.

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Conclusion

A method of calculating complex shape shells of revolution with a layered material structure has been developed on the basis of the displacement method. The method of the structural strength calculating of a combined pressure vessel has been proposed. The structural strength and load capacity of the combined high-pressure vessel, consisting of a CGRP shell, protected from the outside by a metal shell have been investigated.

Recommendations are given to increase the load-carrying capacity of the whole structure and to create the conditions of equal strength of the material of the layered elements without increasing the mass.