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DESIGNING OF METAL-BASE COMPOSITE VESSELS OF HIGH PRESSURE ON THE SET SERVICE LIFE

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Summary. The dependences on determination of longevity of metallic layer in metal-base composite vessels of high pressure have been received in the process of experimental-theoretical research. The model of deforming of the balloon structure, allowing the designing of metal composite vessels of high pressure with the different degree of hybridization of composite layer of minimum mass and costs depending on the appointed service life have been presented in the paper.

Key words: vessel, metal-base plastic, service life, fatigue.

INTRODUCTION

Vessels of high pressure (VHP) are widely used in the different technical systems (gas-fuel equipment of transport vehicles, facilities of rescue, systems of functioning and life-support of man in useless for breathing environment). The feature of vessels, workings under pressure during long time, is a requirement of conservation of their pressure-tightness. Existing presently reinforcing fibres (RF) and the binders possess enough large permeability and, in addition, at loading of vessel by internal pressure (0.1….0.2 from destroying) there is cracking of plastic along fibres. Therefore introduction of layer from isotropous material is needed for creation of pressure-tightness [Obraztsov I.F., 1977], but at the operating loads at expense of a cyclic loading, the considerable deformations occur in such a layer, resulting in fatigue failure of metal. Therefore a research purpose is development of methods of designing and calculation of metal-base composite vessels on the set service life and introduction of results of research into the production of vessels.

OBJECT AND PROBLEMS

It is known [Serensen S.V., 1975.], than higher strength of alloy, the lower its fatigue strength, and than lower strength, so much the better such alloy resists the endurance loads. But, in connection with that alloys with low strength are not used in load-bearing units and there is not information on the fatigue in reference literature, it was required to get fatigue characteristics at from zero loading characteristic for vessels.

The specificity of exploitation of vessels is such that they work in the mode of low-cyclic loading ($10^2 \dots 10^4$) in times of the service life. The ground of it can be following: vessels for the respiratory apparatus of fire brigade on requirements of organs of labor protection of Ukraine must have a service life no less than 2000, in Russia no less than 5000 settings-up [Fire machinery, 2000]. Motor-car vessels for a gaseous fuel must have 15000 preparations (standard of the USA of NGV-2). Vessels for aircrafts must have a service life no less than 5000 preparations [Vessels for aircrafts, 1976].

In connection with absence in reference literature of information on metals in the range of low-cyclic loading, a receipt of such data was required by experimental way. Possibility of experimental verification of bearing capacity of layer in the construction of metal-base composite vessel by the method of measuring of deformations of vessel wall demanded the tests of specimen in the deformation set [Ivanovskaya O.V., 1998], during realization of which the flat stress-strain state of wall of vessel is resulted to uniaxial state on equality of equivalent deformations.

The requirements of «rigid» loading are satisfied by the machines of mechanical loading with a crank-type mechanism. The special testing machine had been designed and made for these purposes [Ivanovskaya O.V., 1998, Ivanovskiy V.S., 1998]. The unit of the controlled amplitude allows fluently to change amplitude of deformation from "0" to 2 мм, with frequency of loading of one hertz. The values of got longevities for the above resulted alloys are presented on a fig. 1.

Results of researches and accumulated experience of some authors, generalized in [Serensen S.V., 1975], on the tests of different metals enable to determine the longevity at cyclic loading on the basis of solution at a single loading. Union between amplitude ε_a of deformation and the number of cycles of N can be presented in the form of equation:

$$N=\left(\frac{\varepsilon_{в}}{\varepsilon_a-\frac{\sigma_{-1}^{0}}{E}}\right)^{\frac{1}{m}}, \tag{1}$$

where: ε_a – relative deformation of a zero semi-cycle,

$\varepsilon_{в}$ – relative lengthening at a break,

m – index of degree, it is taken so that curve *of* $N=f(\varepsilon_{à})$ was more left than experimental points,

σ_{-1}^{0} – fatigue limit at a from-zero loading,

E - modulus of elasticity.

The preliminary analysis of technological properties (weldability, compressability, corrosion resistance) had shown that the followings metallic alloys such as: steel 07X16H6, aluminium alloy of AMg-3, aluminium alloy of AMц-M, steel of austenitic class of 12X18H10T can fit for the production of vessel in the most degree.

The values of curves of fatigue on expression (1) were counted up for the above-mentioned metals.

Analysis of data (a fig. 1) shows that the tested metals have enough wide spread in values of longevity at identical with relative deformations. For example, at relative deformation of 0,3% the expected service life of the Amg-3 alloy will make 400 cycles, and at steel of 12X18H10T are 3980 cycles. It means that a choice of metal for layer is not the least of the factors at the stage at development of vessel construction.

The analysis of technological properties and longevities of specimens of metals has shown that corrosion resistant steel of 12X18H10T meet in the most degree to requirements, produced to layer of metal-base composite vessel, made by the spiral-circular winding of RF.

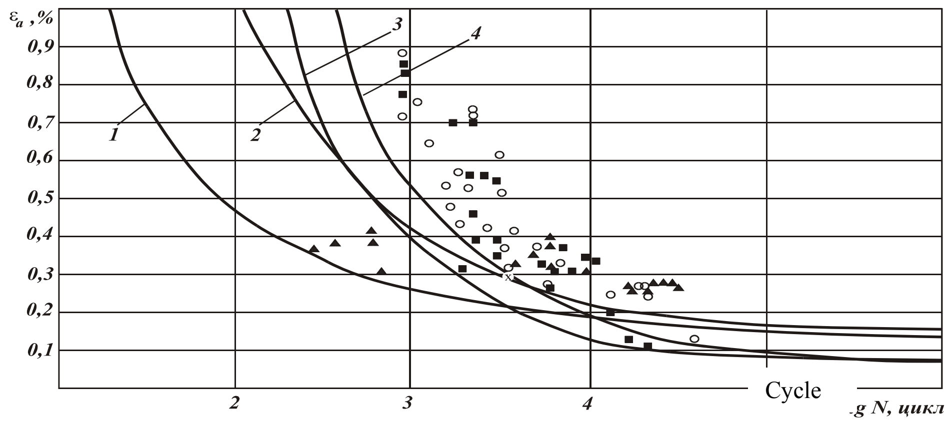

Fig.1. Dependence of longevity of metals on amplitude of relative deformations:
1 – Amg-3; 2 – 07X16H6; 3 - AMц-M; 4 – 12X18H10T;
o - experimental values for steel of 12X18H10T;
□ - experimental values for aluminium alloy of AMц-M;
Δ - experimental values for aluminium alloy of AMg-3

For the vessels of reiterative use the fatigue cracks occur in metallic layer, the cracks disturb its pressure-tightness predetermining its service life. To take into account the influence of tensile deformations in axial $\varepsilon_{ос}$ and annular $\varepsilon_{к}$ directions of layer it is necessary to dispose the uniaxial tensile deformations equivalent to the biaxial deformed state.

Equivalent deformation $\varepsilon_{экв}$ is presented grounded to determine from equality of specific energies of deformation, accumulated in unit of volume at the biaxial loading of vessel layer without a shear and specific energy at its uniaxial loading, resulting in an origin $\varepsilon_{экв}$. [Eger Dg. K., 1961], taking into account that for metals in the elastic state at μ=0.3 we will get:

$$\varepsilon_{eq} = \sqrt{\varepsilon_{oc}^2 + \varepsilon_k^2 + 0.857\varepsilon_{oc}\varepsilon_k} \ . \tag{2}$$

Examining the equilibrium of element of vessel wall (on the base of the cored model), made by winding of spiral and circular layers of reinforcing material on metallic layer, the analytical dependences are got for determination of relative deformations in axial (ε_{oc}) and circular (ε_K) directions, thus the composite layers may be fabricated from different reinforcing materials and laid under different angles to generating line (multi-zone winding):

$$\varepsilon_{oc} = PR\left[\frac{1}{2\left(E_L h_L + \sum E_i^{cn} h_i^{cn} Cos^3\varphi_i\right)} - \frac{\mu}{E_L h_L + \sum E_i^k h_i^k}\right], \tag{3}$$

$$\varepsilon_k = PR\left[\frac{1}{E_L h_L + \sum E_i^k h_i^k} - \frac{\mu}{2\left(E_L h_L + \sum E_i^{cn} h_i^{cn} Cos^3\varphi_i\right)}\right], \tag{4}$$

where: P - pressure in a vessel ,
R - radius of cylindrical part,
E_l -the modulus of elasticity of metal of layer,
h_L - thickness of wall of metallic layer,
E_i^k - the modulus of elasticity of I–th circular layer of RF,
h_i^k - thickness of reinforcing material of I–th circular layer of RF,
E_i^{cn} - the modulus of elasticity of I–того of spiral layer of RF,
h_i^{cn} - thickness of reinforcing material of I–th spiral layer of RF.

Depending on the specific requirements of request for proposal (VHP), predetermining operational conditions of VHP on the appointed service life, mass perfection and minimum cost of the product can have different priority. So for the products, applied in the systems of flying vehicles (FV) of the air-space-purpose, in which cost of 1 kg of flight mass incommensurably higher than technological prime cost of production of the product, a minimum of mass of VHP prevails over the cost of structural materials at equal reliability of the product.

In the wares of the conversional duty (transport, working on the compressed gas, air- breathing apparatus and artificial respirators), a minimum of mass yields to priority of minimum cost of VHP.

All of above-marked testifies to rationality of independent prognostication of characteristics of mass and cost of VHP with subsequent expert adoption of compromise decision. On this basis of such an approach, the method of the rational designing of metal-base composite VHP is got on the set service life, consisting in the following:

Using the dependence of longevity of metal on amplitude of relative deformation (expression (1), fig.1) according to VHP for development of vessel, a necessary service life (amount of preparations of vessel to working pressure) is set, the assumed relative deformation is determined. This deformation in the wall of vessel is provided by winding of necessary thicknesses of reinforcing material in circular and spiral layers. Varying parameters, included in expressions (3), (4), the construction of minimum mass is found, satisfying the appointed service life and cost. The graphs of optimization of vessels of volume of seven litres are resulted on the figures.4,5,6. The vessels are fabricated from different reinforcing materials on working pressure of 29.4 MPa and service life of 5000 cycles at elastic-strength and price characteristics of initial materials resulted in a table 1.

Table 1. **Characteristics of materials used for vessels**

Material characteristics	Fiberglass	Organic fibre (Kevlar)	Carbon fibre	Steel	Binder
Modulus of elasticity, (GPa)	75	125	200	210	------
Tensile strength at tension, (MPa)	1300	2000	2000	520	------
Yield strength at tension, (MPa)	------	-------	------	220	------
Poisson's ratio	------	------	------	0,275	------
Specific mass, (г·см$^{-3}$)	2,5	1,45	1,73	7,8	1,2
Cost, ($./кg)	5	60	60	3	4

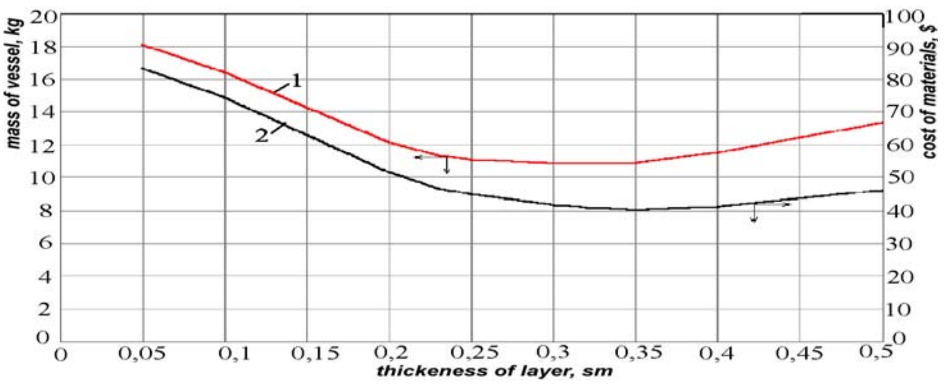

Fig.2. Dependence of mass and cost of materials of vessel, made from glass-reinforced plastic, on the thickness of metal of layer: 1 –mass of vessel, kg; 2 –cost of materials of vessel, dollar

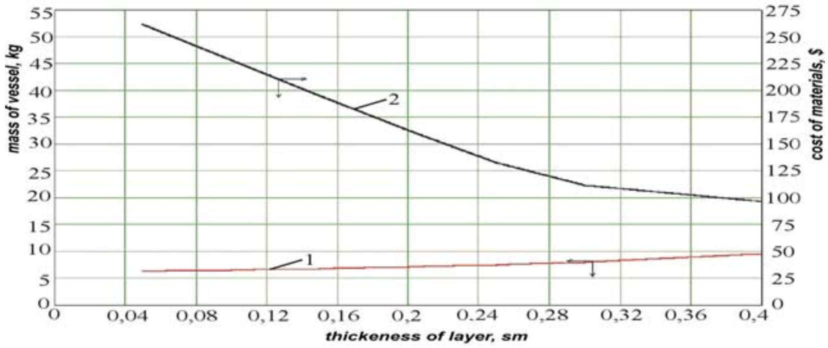

Fig.3. Dependence of mass and cost of materials of vessel, made from organic plastic, on the thickness of metal of layer: 1 –mass of vessel , kg; 2 –cost of materials of vessel, dollar

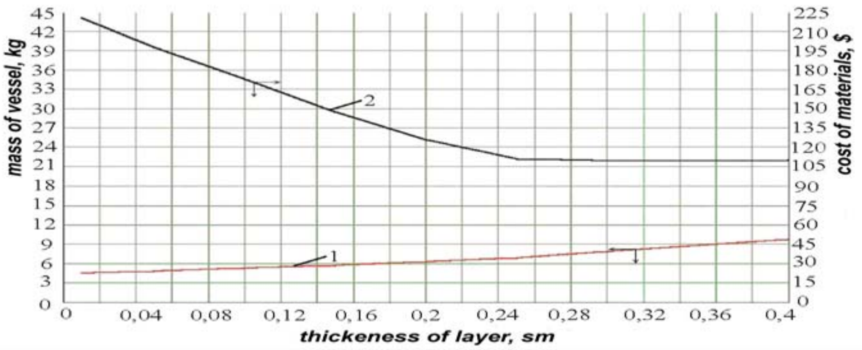

Fig.4. Dependence of mass and cost of materials of vessel, made from carbon plastic, on the thickness of metal of layer: 1 –mass of vessel , kg; 2 cost of materials of vessel , dollar

CONCLUSION

1. The analytical dependence allowing to bring the biaxial deformed state of layer to equivalent uniaxial one on the basis of equality of strain energy and its approximate expression have been obtained. The experimental verification of the expression had shown the accuracy acceptable to VHP.

2. The engineering methodology of determination of longevity of VHP metallic layer is developed. The methodology is based on dependence of longevity with the parameters of single loading of material of layer, satisfactorily concordant with the results of fatigue tests of layer, that allows to use this dependence for designing of VHP on the set service life.

3. The modifications of the cored model of deforming the metal-base composite VHP and analytical dependences for prognostication of equivalent deformation of layer on the early stages of designing for the estimation of potential possibilities of materials

of layer and RF with the different schemes of their hybridization are offered and realized.

4. The considered examples of realization of different design decisions testify to efficiency of the developed methods in the aspect of choice of the proper structural materials depending on the conditions of operation of the vessels. They testify to good experimental confirmation of theoretical results also.

5. The method of the rational designing of metal-base composite VHP is developed on the set service life at the compromise of mass and cost, providing creation of wares of maximal efficiency for FV of different classes and VHP of the conversional purpose.

6. The results of researches are applied in serial industry of metal-base composite VHP for their use in airily-respiratory and reanimation apparatuses[Vehicles, saving life. 2008].

REFERENCES

1. Eger Dg. K., 1961. Resilience, durability and fluidity.
2. Fire machinery. Vessels for respiratory vehicles with the compressed air for firemen / General technical requirements, Methods of tests. NPB 190-2000. M: of MVD of the Russian Federation. Entered with 1.09.2000
3. Ivanovskiy V.S., Ivanovskaya O.V., 1998. Experimental determination of bearing strength of metal-base composite vessels s. / Questions of designing and production of constructions of aircrafts. Proceedings. State Air-Space. University named after of N.E. Zhukovskiy «KhAI». Issue 12. Kharkov: ТО ГАКУ. 77-80.
4. Ivanovskaya O.V., 1998. Experimental research of longevity of alloys for metal-base composite vessels of high-pressure / Questions of designing and production of constructions of aircrafts. Proceedings, KhAI, Issue 10. Kharkov:46-49.
5. Obraztsov I.F., Vasil'ev V.V., Bunakov V.A., 1977. Optimum re-enforcement of shells of rotation from composition materials,(in Russian), Mashinostroenie, Moscow:
6. Serensen S.V., Kogaev V.P., Shneyderovich r.M., 1975. Bearing strength and calculation of details of machines on strength. Guidance and hand-book. Is.3th,(Edited by S.V. Serensen.),(in Russian), Mashinostroenie, Moscow.
7. Vehicles, saving life. 2008:JSC «Horizon». Prospectus of Firm, Lugansk.
8. Vessels for aircrafts, 1976. Specs. APS-6601-00 THAT. NPO «Star», Tomilino, Moscow Region.

ПРОЕКТИРОВАНИЕ МЕТАЛЛОКОМПОЗИТНЫХ БАЛЛОНОВ ВЫСОКОГО ДАВЛЕНИЯ НА ЗАДАННЫЙ РЕСУРС

Ивановский В.С.

Аннотация. В процессе экспериментально-теоретических исследований получены зависимости по определению долговечности металлического лейнера в металлопластиковых баллонах высокого давления. Получена модель деформирования конструкции, позволяющая проектировать баллоны с различной степенью гибридизации композитного слоя минимальной массы и стоимости в зависимости от назначенного ресурса.

Ключевые слова: баллон, металлокомпозит, ресурс, усталость.