Strained-deformation state of polymer composition material shaft of centrifugal pump

Ilman Hasanov

March 23, 2021

Strained-deformation state of polymer composition material shaft of centrifugal pump

#Hasanov Ilman Iman

Baku, Azerbaijan

ilman.hasanov@mail.ru

+ *Department of mechanical engineering and material science, Azerbaijan State Oil and Industry University Avenue Azadlig 20, Baku, Azerbaijan,*

***Abstract*— Combined influence of the tension, torsion and loading of the pressure of the polymer composition material bind for oil field equipment has been considered in the article. Expression for calculation of compressing force in the cylinder of rotating shaft of electrical centrifugal pump has been obtained.**

***Keywords*— tension, torsion moment, deformation, polymer composition, radially.**

I. INTRODUCTION

The use of polymer-composite materials in the nodes of oil and gas production equipment plays an important role in increasing their durability. Composite material (CM), composite is a multi-component material made of two or more components with significantly different physical or chemical properties. In combination, the components lead to the formation of a new material with characteristics that differ from individual components and are not their simple superposition[1,2].

Unlike mixtures and solid solutions, individual components have the same structure as composites. In the content of the composite, it is customary to distinguish the matrix/matrices and filler/fillers. By varying the composition of the matrix and filler, their ratio, and orientation of the filler, a wide range of materials with the required set of properties is obtained. Many composites surpass traditional materials and alloys in their mechanical properties and lightness. The use of composites usually allows to reduce the mass of a structure while maintaining or improving its mechanical characteristics [3,4].

Polymer composition materials are used in many binds of oil field equipment [5]. For example, in the shafts of electrical centrifugal pumps (ECP), and also in ECP components as well as in disc prepared from polymer composite [6], loaded itchy tension, torsion formed, by pressure. Determination off axe symmetric task simplifies the system

$$u = u(r,z)\,;\ \vartheta = \vartheta(r,z)\,;\ u = u(r,z)\,;$$

$$w = w(r,z):$$

$$\nabla^2 u - \frac{u}{r^2} - \frac{2}{r}\cdot\frac{\partial\vartheta}{\partial\theta} + \frac{\partial(s+\alpha_T\cdot T)}{\partial r} + R_r^{/} = 0\,;$$

$$\nabla^2\vartheta - \frac{\vartheta}{r^2} + \frac{2}{r}\cdot\frac{\partial u}{\partial\theta} + \frac{1}{r}\cdot\frac{\partial(s+\alpha_T\cdot T)}{\partial\theta} + R_\theta^{/} = 0\,;$$

$$\nabla^2 w + \frac{\partial(s+\alpha_T\cdot T)}{\partial z} + R_z^{/} = 0;$$

$$\frac{1}{r}\cdot\frac{\partial(ur)}{\partial r} + \frac{1}{r}\cdot\frac{\partial\vartheta}{\partial\theta} + \frac{\partial w}{\partial z} = 3\alpha_T T\,;$$

$$\nabla^2(\cdot) = \frac{1}{r}\cdot\frac{\partial}{\partial r}\cdot\left(r\frac{\partial(\cdot)}{\partial r}\right) + \frac{1}{r^2}\cdot\frac{\partial^2(\cdot)}{\partial\theta^2} + \frac{\partial^2(\cdot)}{\partial z^2}.$$

Then the system takes the form

$$\nabla^2 u - \frac{u}{r^2} + \frac{\partial}{\partial r}\cdot(s+\alpha_T\cdot T) + R_r^{/} = 0\,;$$

$$\nabla^2\vartheta - \frac{\vartheta}{r^2} + R_\theta^{/} = 0\,;$$

$$\nabla^2 w + \frac{\partial}{\partial z}\cdot(s+\alpha_T\cdot T) + R_z^{/} = 0\,;$$

$$\frac{1}{r}\cdot\frac{\partial(ur)}{\partial r} + \frac{\partial w}{\partial z} = 3\alpha_T T\,;$$

$$\nabla^2(\cdot) = \frac{1}{r}\cdot\frac{\partial}{\partial r}\cdot\left(r\frac{\partial(\cdot)}{\partial r}\right) + \frac{\partial^2(\cdot)}{\partial z^2}.$$

In this case, a complex deformed state is created in the polymer composite (disk). For this purpose, it is set to solve in a cylindrical coordinate system (Fig. 1). Figure 1 shows a loading scheme, the consideration of which makes it possible to formulate the following: due to axial symmetry, displacements and w do not depend on the angle

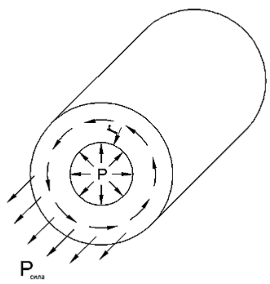

Fig.1. ECP shaft disk made of polymer composite material

Moreover, a fair hypothesis of flat sections is provided, i.e. $w,_r = 0$. Radius changes do not depend on height, therefore, $u_z = 0$. The radii remain straight after deformation, i.e. $\varphi_r = 0$. The derivative φ_z can be considered constant. We denote it by φ . The value of the relative deformation is also constant $1+w,_z$, which will be further denoted by λ : that is, the condition of incompressibility in a cylindrical coordinate system [7]:

$$(r+u) = \begin{vmatrix} 1+\frac{\partial u}{\partial r}; \frac{\partial u}{\partial \theta}; \frac{\partial u}{\partial z} \\ \frac{\partial \varphi}{\partial r}; 1+\frac{\partial \varphi}{\partial \theta}; \frac{\partial \varphi}{\partial z} \\ \frac{\partial w}{\partial r}; \frac{\partial w}{\partial \theta}; 1+\frac{\partial w}{\partial z} \end{vmatrix} = r \quad (1)$$

Taking all this into account, we can write the non-compressibility condition (1) as follows:
Considering all these condition of incompressibility can be written:

$$\lambda + (1+\frac{\partial u}{\partial r})\cdot(1+\frac{u}{r}) = 1 \quad (2)$$

or $(u+r)d\cdot(u+r) = \frac{1}{\lambda} rdr$; $(u+r)^2 = r^2 \cdot \frac{1}{\lambda} + c$ (3)

As $u+r$ >0

Then $$u = \sqrt{c + r^2 \cdot \frac{1}{\lambda}} - r \quad (4)$$

where λ - main deformation.

The energy of deformation is used in the form [8]:

$$W = G \cdot J_1 \quad (5),$$

Where W -is elastic energy; J_1 - deformation invariants; *G*- material shear modulus.

Tension ($\sigma_r^*, \sigma_\theta^*, \sigma_z^*$ and $\tau_{\theta z}^*, \tau_{rz}^*, r_{r\theta}^*$) can be written on the bases:

$$\begin{cases} \sigma_r^* = G\left[(1+u,_r)^2 + \frac{1}{r^2}u,_\theta + u,_{\frac{2}{z}}\right] + S \\ \sigma_\theta^* = G(r+u)^2\left[\varphi,_r + \frac{1}{r^2}(1+\varphi,_\theta)^2 + \varphi,_{\frac{2}{z}}\right] + S \\ \sigma_z^* = G\left[(w,_r + \frac{1}{r^2}) + w,_\theta + (1+w,_z)^2\right] + S \\ \tau_{\theta z}^* = G(r+u)\left[\varphi,_r\, w,_r + \frac{1}{r^2}\cdot w,_\theta(1+\varphi,_\theta) + (1+w,_r)\varphi,_z\right] \\ \tau_{zr}^* = G\left[w,_r(1+u,_r) + \frac{1}{r^2}w,_\theta\, u,_\theta + (1+w,_z)u,_z\right] \\ \tau_{r\theta}^* = G(r+u)\left[(1+u,_r)\varphi,_r + \frac{1}{r^2}\cdot u,_\theta(1+\varphi,_\theta) + u,_z\,\varphi,_z\right] \end{cases} \quad (6)$$

where *G* – displacement module of the material, $\sigma_r^*, \sigma_\theta^*, \sigma_z^*$ -, are correspondingly radial, tangential and axial tension (* - is shown space system of coordinates[9,10]).

If to into (6):

$$\frac{\partial w}{\partial z} = \lambda - 1; \quad (7)$$

$$\frac{\partial w}{\partial r} = \frac{\partial w}{\partial \theta} = \frac{\partial \varphi}{\partial r} = \frac{\partial \delta}{\partial \theta} = \frac{\partial u}{\partial z} = \frac{\partial u}{\partial \theta} = 0$$

$$\frac{\partial \varphi}{\partial z} = \psi ; \frac{\partial u}{\partial r} = \frac{1}{\sqrt{c + r^2 \cdot \frac{1}{\lambda}}} \cdot r \cdot \frac{1}{\lambda} - 1$$

then expression will have the form

$$\begin{cases} \sigma_r^* = G\frac{r^2}{\lambda(c\lambda + r^2)} + S \\ \sigma_z^* = G\lambda^2 + S \\ \sigma_\theta^* = G\frac{1}{\sqrt{c + r^2\frac{1}{\lambda}}}\lambda\cdot\psi \\ \tau_\theta = G\frac{1}{\sqrt{c + r^2\frac{1}{\lambda}}}\lambda\cdot\psi \end{cases} \quad (8)$$

It is impossible to determine constants without revealing the form of function S.

S – is hydrostatic pressure of tension function. Let's consider equilibrium of elementary volume (fig.2). Let's design all forces to direction I- I:

$$(\sigma_r^* + d\sigma_r^*)[r + u + d(u+r)]d\theta - \sigma_r^*(u+r)$$
$$d\theta - 2\sigma_\theta^* d(u+r)\frac{d\theta}{2} = 0 \quad (9)$$

After showing such components, excluding values of second order of smallness and division to $(u+r)dr$ we'll get:

$$\frac{d\sigma_r^*}{dr} + \frac{\sigma_r^* - \sigma_\theta^*}{u+r}(r + \frac{du}{dr}) = 0 \quad (10)$$

Putting expression (10) into expression (9) and considering (8) we'll get differential equation for determination *S(r)*. Let's mention that while integrating new constant c_1 appeared. Constants λ, φ, c and c_1 should be determined from boundary conditions:

$$\sigma_r^*(R_1) = -P_1; \sigma_r^*(R_2) = -P_2 \quad (11)$$

Then we'll:

$$2\pi \int_{R_2+u(R_1)}^{R_1+u(R_2)} \sigma_z^* rdr = P \,;\; 2\pi \int_{R_2+u(R_1)}^{R_1+u(R_2)} \tau_\theta^* r^2 dr = M \quad (12)$$

Let's consider in detail the particular case of tension and of continuous polymer composite cylinder. Boundary condition for $\sigma_r(R_2)$ should be replaced by condition $u(0)=0$, from here follows *c=0*. Then

$$u = c(\frac{1}{\sqrt{\lambda}} - 1) \tag{13}$$

and

$$\sigma_r^* = G\frac{1}{\lambda} + S; \tau_{\theta z}^* = Gr \cdot \sqrt{\lambda} \cdot \psi;$$
$$\sigma_\theta^* = Gr^2(\psi^2 + \frac{1}{r^2}) \cdot \frac{1}{\lambda} + S \tag{14}$$
$$\sigma_z^* = G\lambda^2 + S$$

Differential equation for determination S will have the form:

$$\frac{ds}{dr} - G\psi^2 \cdot r \cdot \frac{1}{\lambda} = 0 \tag{15}$$

Integrating, we'll get:

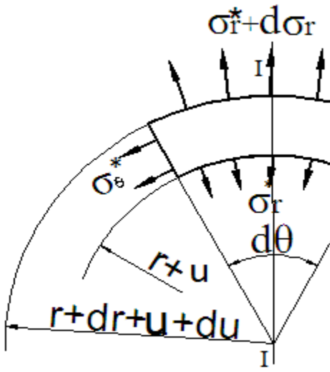

Fig.2. Calculation scheme of polymer composition cylinder

$$S = G\frac{r^2\psi^2}{2\lambda} + c_1 \tag{16}$$

We use the boundary conditions. Of $\sigma^*(R)=0$ follows

$$G \cdot \frac{1}{\lambda} + G \cdot \frac{R^2\psi^2}{2\lambda} + c_1 = 0$$

$$S = G\left[\frac{\psi^2}{2}(r^2 - R^2) - 1\right] \cdot \frac{1}{\lambda} \tag{17}$$

Condition $2\pi \int_0^{R+u(R)} \sigma_z^* r dr = P$

We use boundary condition. Gives

$$P = \pi G\left[R^2(\lambda - \frac{1}{\lambda^2}) + \frac{\psi^2}{4\lambda^3}R^4 - \frac{\psi^2}{2\lambda} - R^4\right] \tag{18}$$

But condition

$$M = 2\pi \int_0^{R+u(R)} \tau_{\theta z}^* r^2 dr \tag{19}$$

Brings to the dependence

$$M = \frac{\pi}{2} G R^4 \frac{1}{\sqrt{\lambda^3}} \cdot \psi \tag{20}$$

Solving equations (18) and (20), together, we find $\psi = \psi(M,P)$ and $\lambda = \lambda(M,P)$

From considered calculations (that's, by description) it follows that, while cylinder torsion the bind of rotating of shaft of ECP cylinder, ($\lambda = 1$) compressing fore occurs:

$$P = -\frac{M}{2r} \cdot \psi \tag{21}$$

Conclusions

Strain- deformation state of the joint action of tension, torsion and loading formed by pressure has been studied. Analytical expressions of compressing force complex loadings in the binds of oil-field equipments (for example, rotating cylinder of the ECP shaft) have been obtained..

References

[1] Катышков Ю.В., и др. Моделирование стадии уплотнения процесса литья. Многоступенчатое уплотнители. Изд. "Химия" "Пластические массы", 1993 г. Научно – технический журнал. № 3, с. 34.

[2] Исследование термических свойств полимер - полимерных композиций на основе полипропилена . Л. Х Кучменова [и др.] . Пластические массы. 2014. № 7/8. - С. 7-9

[3] [3] Kutz M. Applied Plastics Engineering Handbook. Processing and Materials. Elsevier. 2011, 661 p.

[4] Ким В.С. Теория и практика экструзии полимеров.М.:Химия,2005,568 с.

[5] Injection molding handbook. 3 rd edition / Ed. by D.V. Rosato, D.V. Rosato, M.G. Rosato. KluwerAcademicPublishers, 2010. 1457 p.

[6] Osswald T. A., Hernandes-Ortiz J. P. Polymer processing: Modelling and simulation. Munich, Cincinnati: Hanser Publishers, Hanser Gardner Publications, 2006. 633 p.

[7] Mammadov V.T. (2016) Investigation of stress-deformed state of coated hydrocylinders, exposed topressure and temperature changes. International journal of current research, 08 (12), 44212-44216

[8] Разина В.В., Гуров А.А., Смирнов А.Н., Вивюрский А.В. Уплотнительные композиции на основе химически модифицированного ПТФЭ. Изд. "Химия" "Пластические массы", 1991 г. № 10, с.29

[9] Hasanov I., Abbasov I., Gurbanov N. Stress-deformed state of a packing ring with eccentric holes. Proceedings of the Latvian academy of sciences. Section B, Vol. 74 (2020), No. 4 (727), pp. 20–30.

[10] Наушированов Р.Г. Уплотнительная техника, применяемая на нефте- перерабатывающих и нефтехимических производствах в СССР и за рубежом. М., 1991, 61с