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Bohdan V. Kopey*, Stanisław Bednarz, Youy Shuanjui*****

FATIGUE FAILURE STUDY OF FIBERGLASS SUCKER RODS JOINTS

1. INTRODUCTION

The coupling of metallic head with fiber reinforced plastic rod is a constructive necessity in fiberglass sucker rods. Such rod construction is conditioned by technology of oil production with help of pumping units because sucker rod columns often are connected and disconnected during underground repair operations. The steel details work as a protectors and they assure the stiffness of the column. So in this paper we decided to investigate the working performances of sucker rod couplings as joints of steel bandages with polymeric rods, fabricated on the base of fiberglass.

2. DISCUSSION

The anisotropy of composite elastic and strength performances, low interlayer strength, structure heterogeneity lead to worse force transmission from one element of sucker rod to another. The strength of metallic components is higher than this of composite. By means of connection of metallic and composite components one can achieve more reliable construction. All such couplings are manufactured inseparable because metallic detail performs all operations during connection and disconnection [1–5].

The coupling of rod elements are produced by covering one detail part over another in other words in form of male and female construction. The classification of couplings fabricated from metallic and composite rods is presented on the Figure 1.

* National Technical Oil and Gas University, Ivano-Frankivsk, Ukraine
** AGH University of Science and Technology, Faculty of Drilling, Oil and Gas, Krakow, Poland
*** Junma Petroleum Equipment Manufacturing CO., Ltd., China

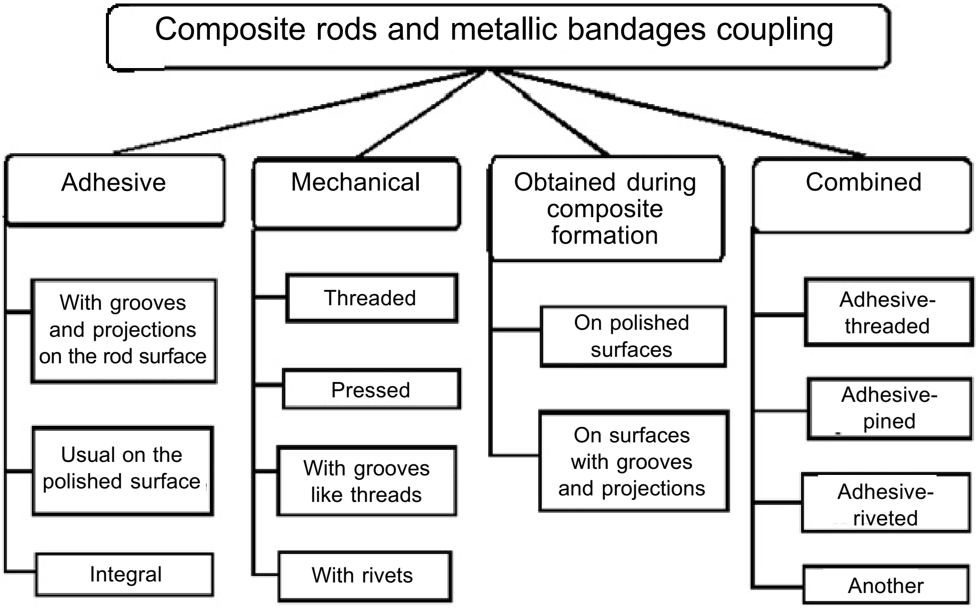

Fig. 1. Fiberglass sucker rod joint's classification

The most spread type of adhesive connections is a joint with polished surface, which needs a high manufacturing steel detail with special grooves or without them. Disadvantage of the method – it is not suitable for hardened resin. The last group presents combined joints. Different combinations of adhesive and mechanical joints raise the strength to 1.2–1.5 times. The up-to-date constructions of fiberglass sucker rods use mainly the adhesive couplings with special wedges in steelhead, which may centralize rod in the bandage, the grooves been filled by adhesive material. The fatigue properties of this joint are determined by adhesive characteristics. Constructive elements of steel bandage such as grooves or projections are the obstacles for adhesive damage and they transform it into cohesive damage, which need bigger energy expenses.

For the connections of metallic and composite materials the epoxy resins and modified epoxy glues are often used. They are simple in production, give a small shrinkage, have a wonderful moisture properties and mechanical performances. The recommended adhesive layer thickness is equal to 0.1–0.2 mm and gives the maximum efficiency of the couplings. The efficiency of above mentioned couplings is determined as a ratio of body rod strength to joint strength under axial loading. This estimation parameter for adhesive joint of Chinese sucker rods (Shashi steel pipe works) equals to 7:4 [8]. We have proposed the mechanical joints of steel head with polymeric rod by pressed method. The strength of sucker rod of 22 mm gave the efficiency of coupling equal to 5:2. The character of damage has mixed features: in 50% of fracture cases we observed the whole slippage out of rod from the bandage, in 50% – partial strip of surface layers of polymeric rod.

An apparatus for fatigue testing of sucker rods under cyclic bending has been designed [9]. Based on the results of experiments the following conclusions were made. When cyclic bending stresses achieved the values of 140 and 120 MPa then the test sample fiberglass sucker rods broke at the joins with steel heads fiberglass body, thus they withstand 0.034 and 0.114 mln cycles respectively. This indicates that these fiberglass sucker rod are unable to withstand relatively high bending stresses. When bending stress was 90 MPa the sample broke at the joint with steel heads fiberglass body, passed with 1.298 mln cycles. This result is acceptable and fit the earely conducted studies.

When bending stress achieved 100 MPa and 80 MPa respectively the fatigue life was 3.091 and 5.955 million cycles but they have not been broken, but there were numerous fatigue cracks and delaminations. These results indicate that these fiberglass rod can easily withstand bending stresses up to 80–100 MPa.

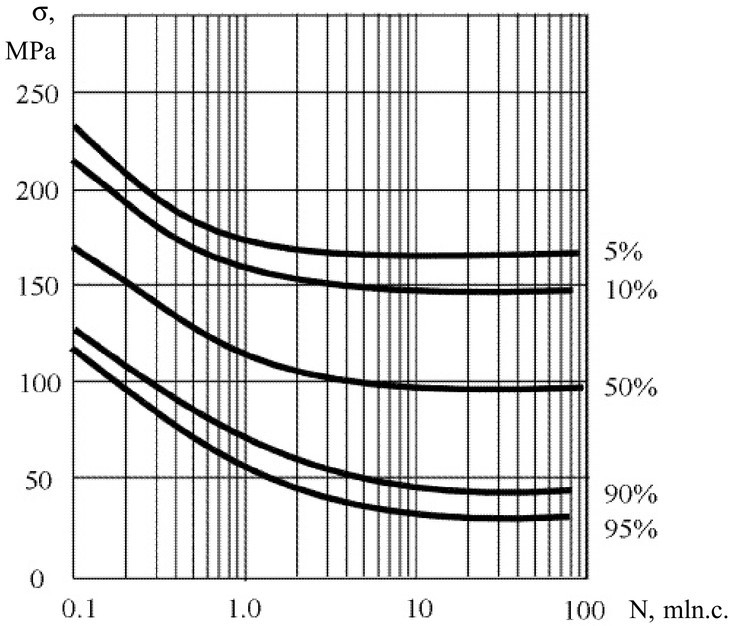

Fig. 2. Wohler fatigue curves of different probability of 22 mm fiberglass sucker rods

The fatigue tests of fiberglass sucker rods (22 mm in diameter) under symmetric bending in oil acidic solution (10% of HCl) showed a sufficiently high strength. The fatigue limit with 50% of probability of non-destruction equals to 100 MPa on the basic number of cycles N = 10 mln. (Fig. 2).The character of damage depends on the value of applied bending load. At the high level of cyclic stresses (130–150 MPa) the damage is localized in the rod body at the distance of 50–100 mm from the head and is characterized by intensive delamination of the fiberglass rod, i.e. the damage of matrix or debonding of matrix-fiber interface is in the nature of fatigue destruction. It may be explained by the fact that the slope of fatigue curve for the matrix and interface adhesion is less than for the fiber. Why the delamination is localized at the certain distance from the head? It is explained by strengthening of the rod during bandage compressing around the composite body by increase of fiber-matrix adhesion. Due to the fibrous structure of the composite rod with certain stiffness the stresses are generated out of the bandage limits falling to zero at the distance of 50–100 mm. But when the cyclic stresses decrease to values of 100–120 MPa and lower the place of damage is localized just in the place of composite body compressing. On the surface of fracture one can observe irregular breaks of fibers without any delamination of specimen. This place is a stress concentrator due to bandage penetration and some partial cuttings of fibers during compressing.

After analyzing the present investigation we have obtained the function of stress--cycles σ-*N* depending with coefficient of data approximation $R2 = 0.8931$:

$$\sigma = 372.2 \cdot N - 0.096.$$

In the study of damaged samples we revealed many defects and cracks.

For samples that worked with bending stresses 80, 90 and 100 MPa were found the cracks of different lengths presented in Table 1.

Table 1

Length of cracks in tested samples

Bending stresses σ, MPa	Crack length *L*, mm			
80	5	25	42	45
90	36	37	–	–
100	9	11	–	–

The function of the length of cracks *L* depending on the bending stresses σ is expressed with the approximation $R2 = 0.8284$ (Fig. 3):

$$L = 13 \cdot \sigma - 6.222.$$

Realization of contact interaction conditions taking into consideration will lead us to the following integral equation for determining of the contact pressure $q\,(x)$ [2]:

$$kq(x)+\int_0^x g_{13}(x-s)q(s)ds=\overline{\varepsilon}+y_1(x)\int_0^a g_{43}(L-s)q(s)ds+ \\ +y_2(x)\int_0^a \left(g_{23}(L-s)+g_{33}(L-s)\right)q(s)ds \quad (1)$$

where:

k – constant coefficient,

ε – value of relative shrinkage during steel head deformation,

$L = l/R$ – dimensionless length of the rod,

$y_1(x), y_2(x)$ – certain functions expressed through $g_{13}(x)$, $g_{14}(x)$ and the found constants $c_1, ..., c_4$ (expressions for them are not given because they are quite complex).

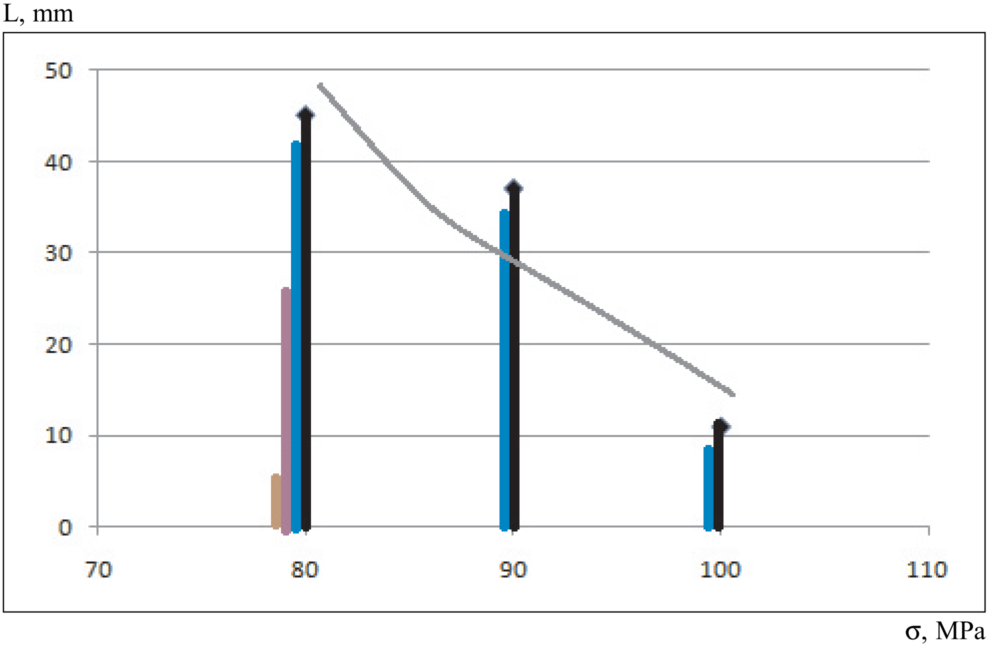

Fig. 3. Plot of lengths of cracks L depending on the bending stresses σ

The resulting integral equation (1) is reduced to linear homogeneous transformation II degree Fredholm equations with discontinuous core.

$$q(x)+\int_0^a K(x,s)q(s)\,ds=\frac{\overline{\varepsilon}}{k} \tag{2}$$

where:

$$K_1(x,s)=g_{13}(x-s),$$

$$K_2(x, s) = y_1(x)g_{43}(L-s) + y_2(x)(g_{23}(L-s) - g_{33}(L-s)) \tag{3}$$

The requirement for the interrupted core of the integral Fredholm equation of second degree is fulfilled in this case because of properties of function $g_{ij}(x)$. In order to solve the integral equation with core we use the method of square formulas, which allows reducing the problem to finding a solution for an approximating system of algebraic equations. For example, while using the trapezium formula with the constant step ($h_i = h =$ const) of integration interval division [0, a] we get the following system of equations for solutions $q(x)$ values $q(x_i) = q_i$ in points $x_i, x_2, ..., x_n$:

$$q_i - h \sum_{j=1}^{n} A_j K_{ij} q_j = F_i \quad (i = 1, ..., n) \tag{4}$$

where:

$n = a/h + 1$ – the number of points,

$F_i = \dfrac{\overline{\varepsilon}}{k} = \text{const},$

$K_{ij} = K(x_i, x_j),$

$$A_j = \begin{cases} 0.5, \text{when } j = 1, \text{ and } j = n, \\ 1, \text{when } j \neq 1, \text{ and } j \neq n \end{cases} \tag{5}$$

As a result of solving a system of linear algebraic equations we get $q_1, q_2, ..., q_n$, according to which, using interpolation method we find the approximate solution of the equation (2) on the whole section [0, a]. So the following represents the analytical expression of the approximate solution of the problem:

$$q(x) \approx \frac{\overline{\varepsilon}}{k} + \sum_{j=1}^{n} A_j K(x, x_j) q_j \tag{6}$$

which at the points $x_1, x_2, \ldots, x_n$ has the values $q_1, q_2, \ldots, q_n$.

3. CONCLUSION

So, in the article the performance of fiberglass sucker rods under the action of bending loads was presented and analyzed, using a method of full-scale fatigue testing. The functions depending on the length of the cracks and fatigue strength of fiberglass sucker rods on the size console bending stresses were obtained.

Based on the found contact problem solving using computers strength characteristics of the compounds were analyzed, dependence of contact pressure on the value of shear compliances of shell material, orthotropy option, size of joint were obtained. It was found that the greatest contact pressures occur at the edges of the shell, and they are distributed evenly along the length of the shell at higher values of orthotropy parameter E_1/E_2 and shifting susceptibility option E_1/G'. The most affected on the value of grip is the width of bandage.

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