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Research and Development of Tubular Composite Sucker Rods

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Abstract:

A new design of tubular sucker rods made of fiberglass and carbonfiber have been developed for application in oil production. The results of static tensile tests of samples with a new tubular fiberglass rod and usual solid fiberglass rod are presented. Static tests of samples cut from the rod body were also carried out under cantilever bending. Fatigue curves were obtained and fatigue limits were determined: for solid fiberglass sucker rods of a conventional design, for hollow fiberglass sucker rods, for reinforced fiberglass rods and for hollow carbonfiber rods as well as for hybrid rods. A finite element model was constructed to evaluate the stress state of the wedge-glue joint. The authors propose to use the finite element method to find the optimal compression force between tube and steel head. Based on tests of prototypes and FEM, the optimal connection parameters were found.

Keywords: hollow rods, fiberglass rods, carbonfiber rod, hybrid rod, modelling, FEM method

1. Introduction

The extraction of hydrocarbons from mature oil reservoirs increasingly relies on artificial lift systems to sustain production rates as natural reservoir pressure declines [1]. Among these systems, rod pumping (also known as beam pumping), remains the most widely adopted method globally, accounting for over 80% of artificial lift applications [2, 3] due to its reliability and adaptability. At the heart of this technology are sucker rods [4], which form the mechanical linkage between the surface pumping unit and the downhole pump, transmitting cyclic tensile loads to facilitate fluid production. For decades, conventional steel sucker rods have dominated the industry, yet their performance is increasingly challenged by harsh operational environments. Exposure to corrosive fluids, high-cycle fatigue, and elevated temperatures often leads to premature failures, costly workovers, and production downtime. Moreover, the substantial weight of steel rods contributes to elevated energy consumption and limits their application in deeper or deviated wells. In recent years, composite materials [5, 6] have emerged as a promising alternative to steel, offering inherent advantages such as high strength-to-weight ratios, corrosion resistance, and tailored fatigue performance. Early iterations of composite sucker rods, typically constructed from fiber-reinforced polymers (e.g., carbon or fiberglass epoxy matrices), demonstrated potential in reducing rod string weight and mitigating corrosion-related failures. However, challenges persist in optimizing their structural design to match the mechanical demands of dynamic downhole conditions while maximizing economic viability [7, 8] or use it as a novelty technique of Industry 4.0 equipment in hydrocarbons extraction [9].

This study introduces the fiberglass tubular composite sucker rods (TCSR) [10], build from polymeric composite materials (PCM) an innovative redesign leveraging the anisotropic properties of composites as fiberglass through a hollow cylindrical geometry [3] with use FEM analysis in what is present and often found in the mining industry [11]. Unlike solid composite rods, the tubular configuration reduces material usage without compromising load-bearing capacity, further lowering weight and minimizing fluid drag forces during operation. Additionally, the closed-section design enhances resistance to buckling and improves stress distribution under cyclic loading. While prior research has explored composite rods, the unique benefits of tubular geometries such as enhanced fluid flow dynamics, reduced friction, and improved compatibility with existing wellbore infrastructure, remain underexplored in both experimental and operational contexts. The implications of this research extend beyond operational efficiency; TCSRs have the potential to reduce energy consumption, lower maintenance costs, and extend the lifespan of aging wells, particularly in corrosive or high-temperature reservoirs. Furthermore, the reduced environmental footprint of composite materials aligns with growing industry emphasis on sustainable practices. This article presents a critical step toward redefining sucker rod technology, offering insights that bridge material science innovation with practical oilfield applications.

2. Fiberglas static tests and examinations

The results of static tensile tests of samples with a new tubular fiberglass rod show that their proportionality limit is σ_{pr} = 381 MPa, and the ultimate strength is σ_{B} = 502 MPa (Fig. 1b). The nature of the failure of the samples is as follows. At the points of fastening, displacement is observed, and in the middle part - splitting of fibers. Rupture along the body was not observed. Upon reaching a stress of about 330-350 MPa, delamination of the material was observed at the points of fastening of the sample. When testing new solid fiberglass sucker rods, the proportionality limits σ_{pr} = 381 MPa and the ultimate strength σ_{B} = 514 MPa were determined (Fig. 1a).

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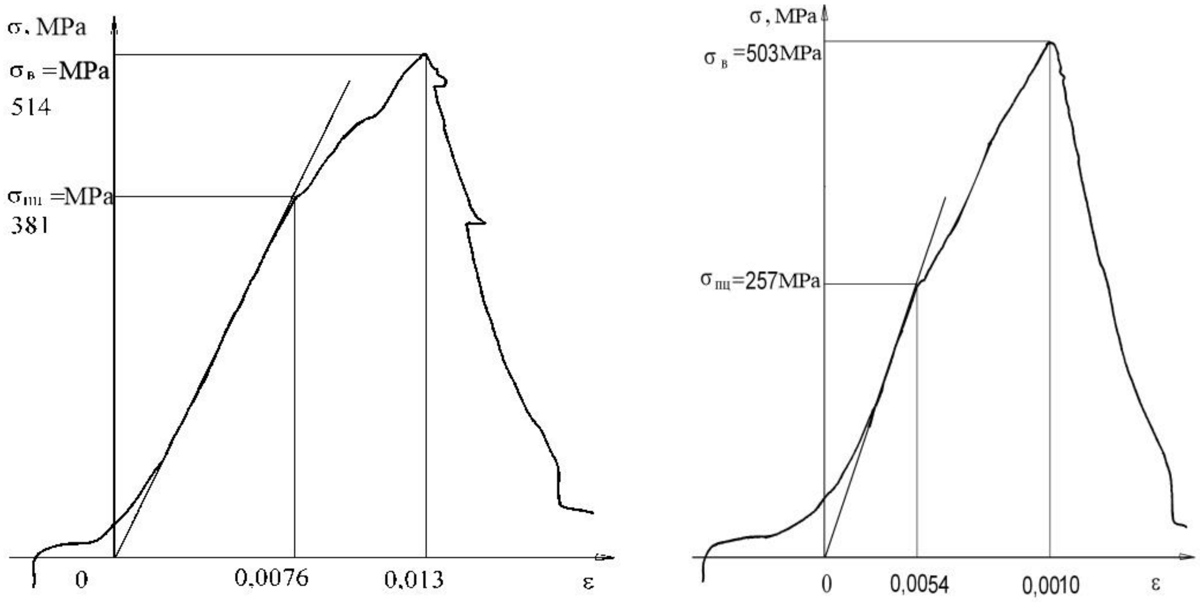


a b

Fig. 1. Tensile diagram of samples of new solid fiberglass sucker rod (a) and new tubular fiberglass sucker rod (b)

Static tests of samples cut from the rod body were also carried out under cantilever bending. At a stress of about 200 MPa, characteristic cracks appeared at the point of clamping, indicating the onset of composite failure. Particularly dangerous for fiberglass rods is their operation under cyclic bending conditions [12-15]. Compression loads acting on the rod column can lead to bending of the bottom of the column and cause bending stresses, the highest values of which are localized at a distance of 200 mm from the rod head. Most often, breakages of both steel and fiberglass sucker rods along the body occur precisely in this place. In fiberglass rods, at the same time, the polymer binder is first destroyed, and then individual fibers break. A fiberglass rod destroyed in this way is difficult to carry out fishing operations. Fig. 2 shows a typical breakage of the body of a solid fiberglass rod when the column is subjected to compression loads.

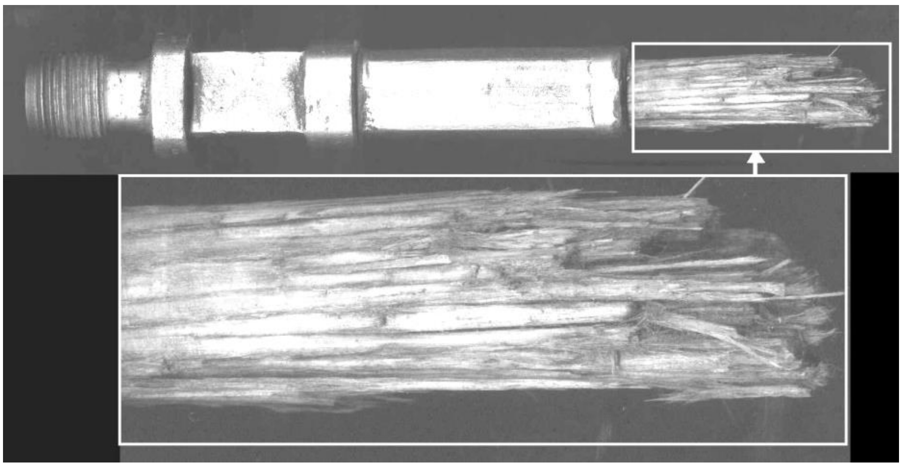


Fig. 2. Typical fracture of a fiberglass rod along the body

Especially dangerous for fiberglass rods is their work in conditions of cyclic bending [12-15]. Fatigue curves were obtained and fatigue limits were determined: for solid fiberglass sucker rods of a conventional design in formation water with oil, hollow in mineralized formation water, for reinforced fiberglass in oil with 10% HCl (Fig. 3). The fatigue curves σ – N obtained during the test for cantilever bending of samples from composite (reinforced with glass fibers or carbon fibers), hybrid [15] and steel sucker rods [14] were compared with each other. With a test base of 2×107 cycles, hybrid sucker rods with a carbon fiber reinforced core and a glass fiber reinforced shell have the highest level of conditional fatigue limit – 110 MPa.

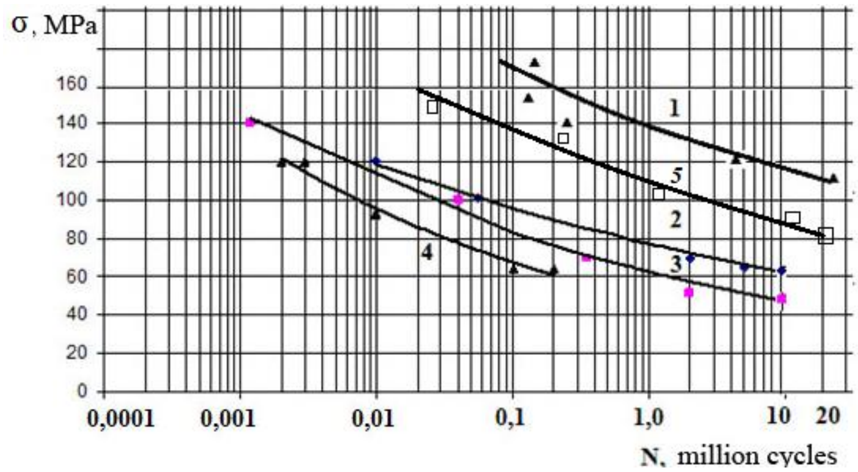


Fig. 3. Fatigue resistance curves of hybrid sucker rods (1), fiberglass (2-4) and carbon fiber (5) during cyclic bending: 1 - hybrid rods in mineralized formation water, 2 - hollow original design in oil with 10% HCl, 3 - reinforced design in formation water with oil, 4 - usual design in mineralized formation water, 5 - hollow carbon fiber UKN / 5000 modified by atmospheric plasma treatment with acrylic acid original design sucker rod in mineralized formation water

Fiberglass sucker rod samples were tested for resistance to fatigue failure under cyclic bending. Fatigue curves were obtained and fatigue limits were determined: for solid fiberglass sucker rods of conventional design in formation water with oil, in mineralized formation water, for hollow fiberglass composite materials of reinforced design - in oil with 10% HCl (Fig. 3). On the Figure 4 were showed the view of destroyed samples.


a


b

Fig. 4. Specimens after static tensile strength testing (a) and cyclic bending (b) Increasing the strength of the connection between the fiberglass body of the sucker rod and the steel head

3. The Fiberglass modelling method

A finite element model was constructed to evaluate the stress state of the wedge-glue joint for a 22 mm diameter rod. The steel head (Fig. 5) has the following mechanical properties: elastic modulus E = 2.1 10^{11} Pa, Poisson's ratio ν = 0.28;· fiberglass ·body: elastic modulus in the axial direction Ey = 0.5 10^{11} Pa, ν = 0.22; $\nu 10^{11}$ Pa, in the radial direction Ex=0.1·10^{11} Pa, ν_{xy}=0.22, ·polymer wedges: E=3.8·10^9 Pa, ν=0.33.

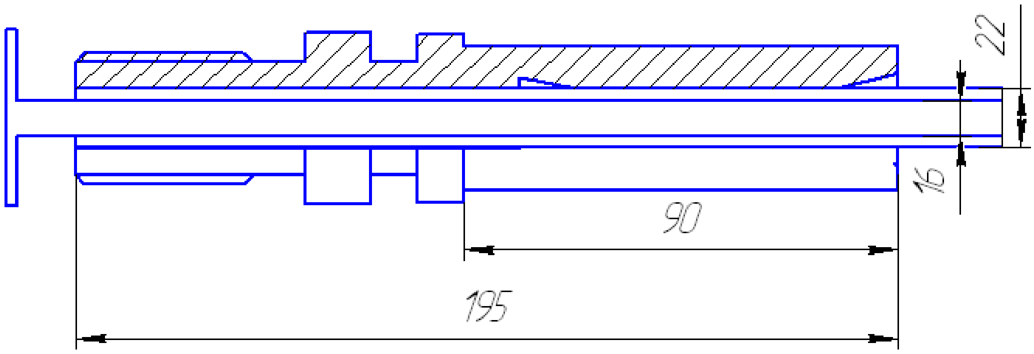


Fig. 5. Design of the sucker rod head for a wedge-adhesive joint

When an external tensile load is applied to the wedge-adhesive joint of a rod with a diameter of 22 mm, which corresponds to a stress in the rod body of 500 MPa, it is noticeable that the first and last wedge of the joint are the most loaded (Fig. 6a).

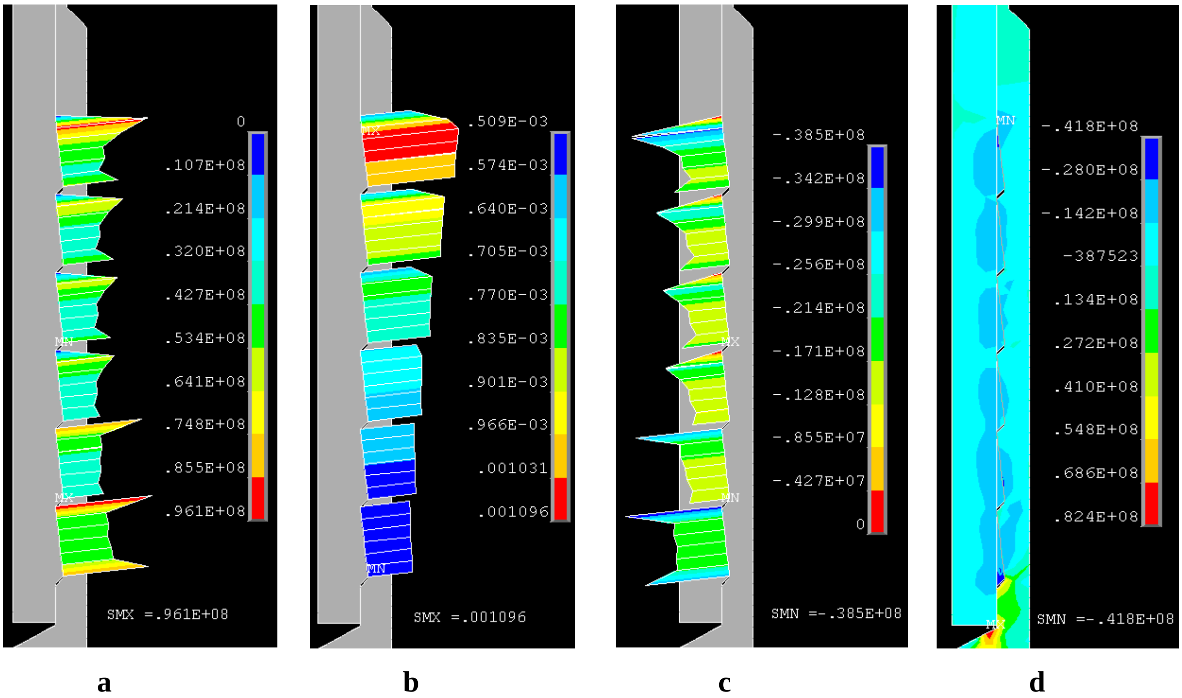


Fig. 6. Characteristics of a wedge-adhesive joint of a rod with a diameter of 22 mm at an external load of 500 MPa contact pressure, MPa (a), slip value, m (b); shear stress, MPa (c) in the area of contact of the head with the wedges; τxy, MPa (d) distribution of tangential stresses

The contact pressure here reaches 96 MPa, which can lead to the destruction of the polymer wedges. The greatest value of sliding in the area of contact with the head is observed at the first wedge (Fig. 6b). If the strength of the adhesive joint under shear is 20 MPa, then destruction of the adhesive bond between the first and last two wedges and the steel head is possible (Fig. 6c). The shear stress between the fiberglass rod and the wedges is distributed almost uniformly and is equal to 14-28 MPa (Fig. 6d). However, it has been established [14] that adhesion does not play an important role in the strength of the joint. Therefore, the main criterion for the strength of such a connection is the strength of the wedge itself and the uniformity of the load distribution between the wedges. To determine the load distribution between the wedges of the connection, at different values of the external load, tensile stresses were gradually changed from 100 to 500 MPa. At a load corresponding to a tensile stress of 100-200 MPa in the body of the rod, the first wedge bears the greatest load, and at a load of 400-500 MPa - the last one (Fig. 7). The load is distributed most uniformly between the wedges at an external load of 300 MPa.

Considering that in practice the fiberglass sucker rod takes tensile stresses less than 300 MPa, it is necessary to provide in the design elements that would reduce the load on the first wedge. This can be achieved, for example, by decreasing its angle. Designs of a wedge detachable connection [14] (Fig. 8a) and a detachable connection with a screw insert [14] (Fig. 8b) have been developed, which allow the reuse of the head in case of failure of the rod body.

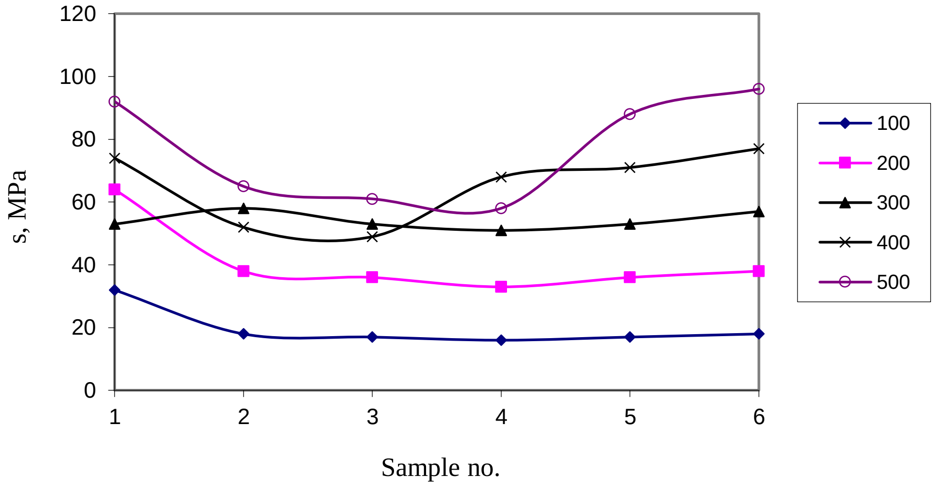


Fig. 7. Maximum value of contact pressure in the areas of contact of the head with the wedges at different values of external load (MPa)

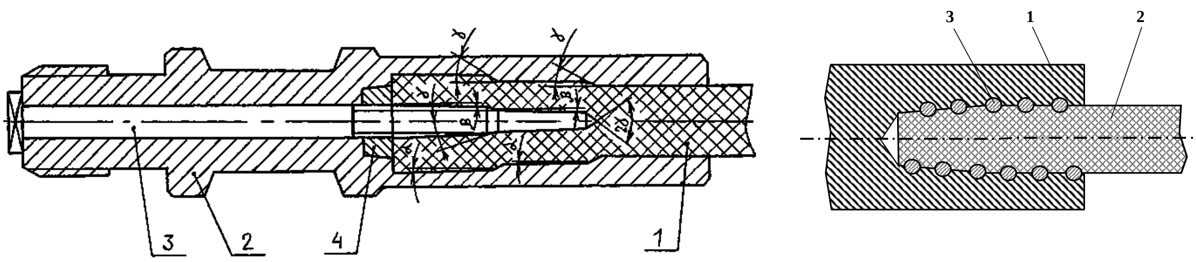


Fig. 8. Designs of wedge-type detachable joints (first from the left side) and with screw insert (secenod from the left side)

4. Prepared model discussion

At present time, a mathematical model of the contact interaction of the rod body and the steel head has been developed, which allows studying the distribution of contact stresses depending on the mechanical and geometric properties of the press connection. However, for practical use, the model is quite complex. The authors propose to use the finite element method to find the optimal compression force (with a known geometry of the connection and materials), which is relatively easy to implement on a computer. Geometrical parameters of the connection: fiberglass body diameter - 22 mm, head outer diameter - 32 mm, contact length - 90 mm, compression length - 80 mm. On the contact surface of the axisymmetric model, the possibility of their mutual movement and the friction coefficient ft = 0.1 are specified, for the head material the mechanical characteristics are E = 2.1 · 10·Pa, ν = 0.28, σт = 4.2 · 108 Pa, and for the fiberglass body material the orthotropy parameters are: Ey = 0.5 · 1011, the modulus of elasticity in the axial direction Ex = 0.1 · 1011 Pa, νxy = 0.22, in the radial direction Ex = 0.1 · 1011 Pa, νxy = 0.22. To find the parameters of contact interaction that determine the strength of the connection at different compression forces and different levels of axial load, the following algorithm was used (Fig. 9). First, the compression pressure Px was set on the surface of the bandage. If the compression pressure in the body of the fiberglass rod causes a stress σx less than the yield strength σxт, the value of the external tensile load F was set. If F is less than the critical Fcr (determined by the tensile diagram of the connection), it was increased by a step ΔF until F reached the value Fcr. P was increased by a step ΔP until the optimal compression force was found.

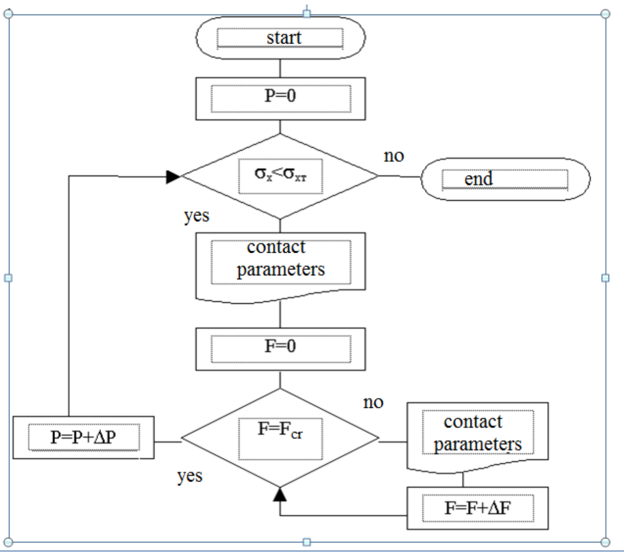
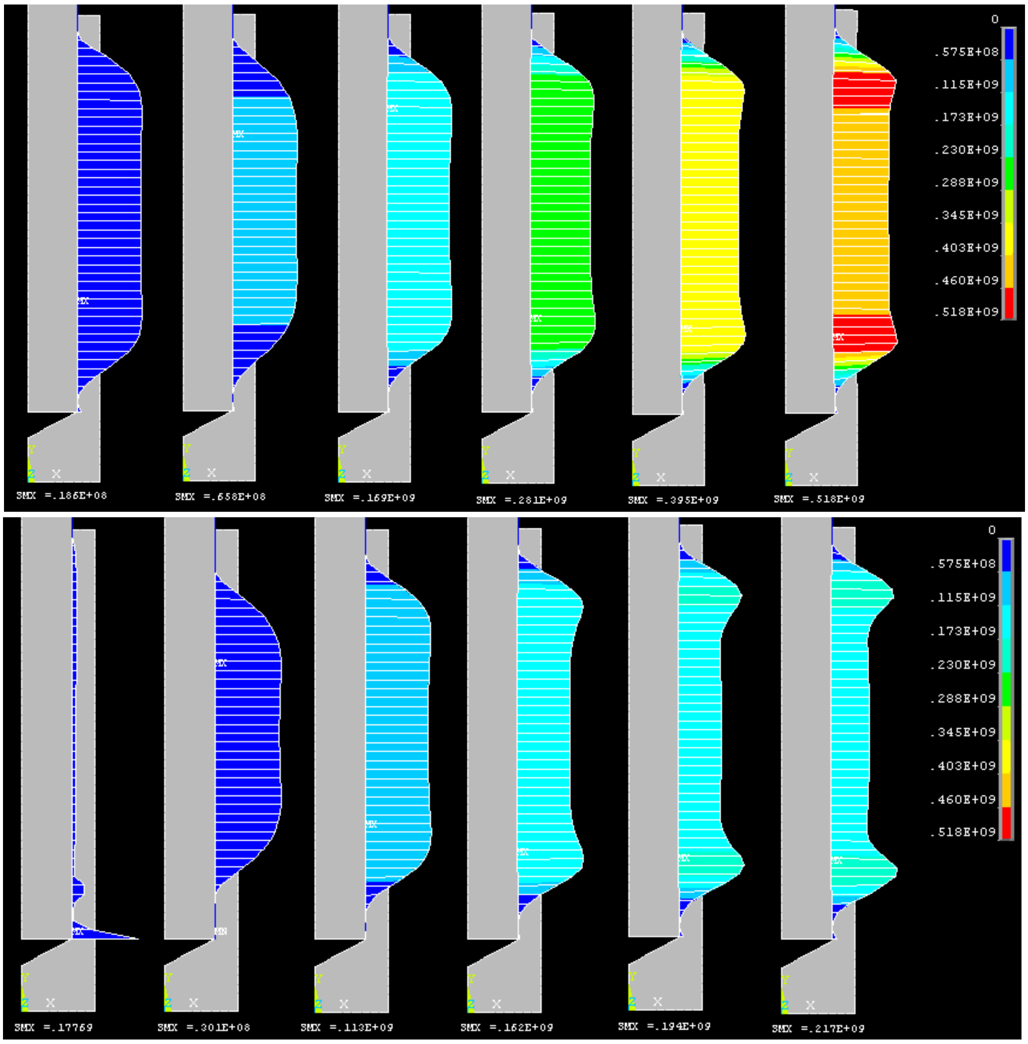


Fig. 9. Scheme of the algorithm for optimizing the compression force: P - compression pressure; ΔP - step of changing the compression pressure; F - external axial load; ΔF - step of changing the axial load; Fcr - critical value of the external axial load; σx, σxt - stresses and yield strength in the radial direction of the fiberglass rod

Figure 10 shows the distribution of contact pressure in the joint during compression (a) and after it (b) and compression forces: 100, 200, 300, 400, 500, 600 MPa, respectively. The maximum tensile load is 500 MPa, provided $\sigma_x<\sigma_{xT}$, achieved when crimping the steel head with a force of 400 MPa. It should be noted that in practice, compression is not carried out uniformly, but from 6-8 sides of the steel head. Therefore, in order to check the conformity of the model to the real connection, a full-scale sample of a rod connection with a diameter of 22 mm and a reduced model of it with a fiberglass rod diameter of 9 mm were made and tested for static tension. When crimped with a force of 400 MPa, the full-scale sample withstood the maximum tensile load of 365 MPa, and the sample with a rod diameter of 9 mm - 340 MPa. After examining the fiberglass rod torn out of the head, a thin layer of cracked material was found on the surface, the presence of which caused a significant decrease in strength compared to the model. Assuming that this layer could have formed during the crimping of the steel bandage, some changes in the joining technology are proposed. From Fig. 10 it is evident that the contact stresses during crimping with a force of 400 MPa reach 288 MPa, and after crimping they decrease to 173 MPa.



a

b

Fig. 10. Distribution of contact pressure along the length of the contact at the moment of compression (a) and after compression (b) at a compression pressure of 100, 200, 300, 400, 500, 600 MPa, respectively

If the fiberglass rod is heated before the start of compression, thereby reducing its elastic modulus, then cracking of the surface layer can be prevented. Additional use of glue in the joint will strengthen the surface layer. The strength of joints manufactured with such changes in technology increased to 480 MPa (rod diameter 22 mm) and 460 MPa (rod diameter 9 mm).

The press connection method requires careful attention to such parameters as the yield strength σ_{XT} and the elastic modulus E_x of the fiberglass rod. Thus, the author experimentally established that when compressing fiberglass rods, the polymer component of which has lost its original strength characteristics due to long-term exposure to the environment and temperature, the strength of the connection is significantly reduced. Such a connection, with a rod diameter of 9 mm, when

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compressed with straight dies with a force of 400 MPa, does not withstand a tensile load of more than 270 MPa. Additional use of glue in a connection of this type will not only increase the strength of the connection, but also ensure that the environment does not penetrate into the contact area. When designing a connection of this type, it is important to identify the locations in the steel band where a fatigue crack may initiate. The mark left by the stamp on the head surface may cause a crack to initiate. Figure 11 shows the distribution of the fatigue safety factor D for the volumetric stress state under uniform compression with a force of 400 MPa and a change in the axial tensile load from 0 to 250 MPa.

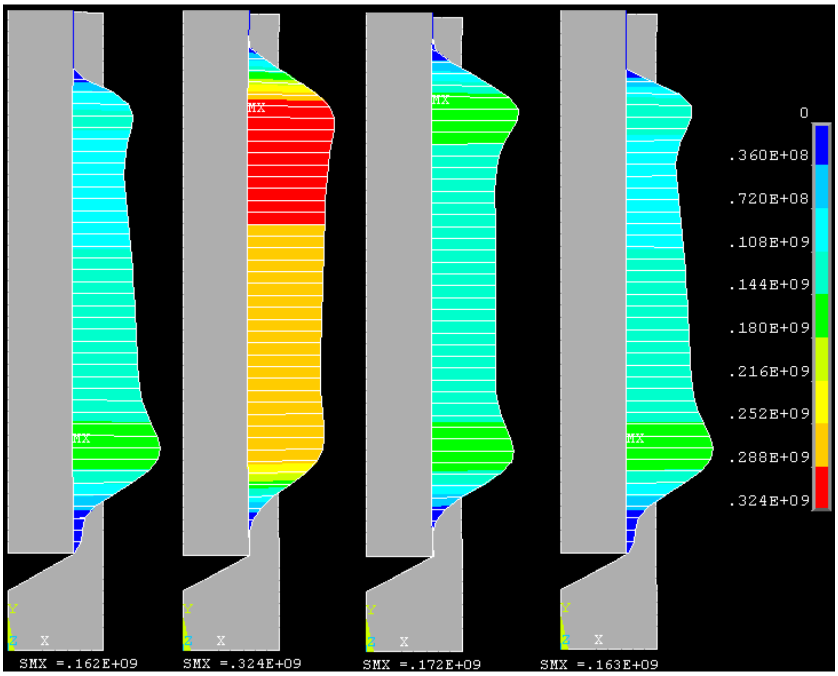

Fig. 11. Distribution of contact pressure along the length of contact during compression with straight (a – first from the left) and inclined (b, c, d – from the left next accordingly) dies: at the moment of compression (b), after compression (c) and at the moment of reaching a tensile load of 500 MPa (a - d)

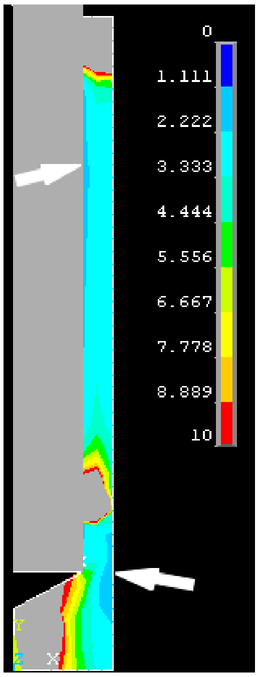

Fig. 12. Distribution of the fatigue safety factor D during uniform compression with a force of 400 MPa and a change in axial load from 0 to 250 MPa

As can be seen, the most dangerous zone is located near the place where the die begins to contact the bandage (shown by arrows). To reduce the risk of cracking, dies with rounded edges should be used.

5. Conclusion

- Static tension and compression tests of new and used fiberglass sucker rods allowed us to evaluate the change in their mechanical characteristics after two years of operation: the proportionality limit under tension decreases by 24 MPa, and the ultimate strength by 18 MPa, the ultimate strength under compression along the fibers decreases by 33 MPa, and under compression across the fibers by 16 MPa. This proves the need to protect the rod body connections with the head from environmental influences.

- Corrosion fatigue tests of fiberglass sucker rods under cyclic bending allowed us to determine the corrosion fatigue limits: for a rod of conventional design in formation water with oil, in mineralized formation water, and for hollow rods of reinforced design in oil with 10% HCl. The fatigue dispersion characteristics of sucker rods were calculated. It was shown that fiberglass rods of reinforced design can be used under conditions of increased bending and compression loads.
- It is not recommended to equip the rods with movable scrapers at low intensity of paraffin on the rod body.
- Using the developed finite element models of wedge-glue and press joints of the body of a fiberglass rod with a steel head, the stress-strain state of the joints at various levels of external load was analyzed. Based on tests of prototypes and FEM, the optimal connection parameters were found. Designs were developed and recommendations were given for improving the manufacturing technology of fiberglass sucker rods.

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