A. D. MEKHTIYEV, A. A. KOVTUN, V. V. YUGAY, E. G. NESHINA, R. ZH. AIMAGAMBETOVA, A. D. ALKINA

ISSN 0543-5846
METABK 60(1-2) 121-124 (2021)
UDC – UDK 622.362:535.8/621-49:539.417:62.001.57-66.019:531-620.16 = 111

RESEARCH OF MECHANICAL STRESS AT TENSION OF QUARTZ OPTICAL FIBER (QOF)

Received – Primljeno: 2020-08-27
Accepted – Prihvaćeno: 2020-10-25
Preliminary Note – Prethodno priopćenje

The article presents the results of a study of the process of occurrence of mechanical stress and strain during stretching of a quartz optical fiber. The analysis and review of the current state of development of fiber-optic conductors is performed. The problems of occurrence of microcracks in the body of optical fibers during mechanical loading during operation are considered. In the process of winding optical fibers and further operation, cracks occur. The conducted research allows us to solve an important production problem related to increasing the strength of optical fibers and reducing the number of microcracks. The object of scientific research is quartz optical fiber of the G652 standard, used for the production of fiber-optic cables. For optical fibers, the greatest danger is the stretching, which is observed when rewinding the fiber, during its cabling, during the laying and operation of the optical cable. It was found that the mechanical tensile strength of G652 optical fiber was from 4 482 to 4 808 MPa, and the number of cracks and their parameters affect the tensile strength of the fiber.

Keywords: quartz, optical fiber, stretching, crack, fatigue crack modeling, mechanical stresses

INTRODUCTION

Optical fiber (OF) has been used to transmit information for over 35 years. Optical fiber has an operating frequency range that provides information data transmission more than a hundred times more than the radio airwaves. The material of modern optical fibers operates with light wavelengths of 850, 1 300, 1 310, 1 550 nm [1, 2]. In 1 966, English scientists Cao and Hockham removed the impurities of transition (“dye”) metals from quartz glass.

This made it possible to achieve a decrease in the level of optical radiation energy losses and to obtain losses of less than 20 dB/km. For this discovery and obtaining new material, they were later awarded the Nobel Prize [2, 3]. In 1 973 – 1 974, engineers from Bell-Labs and Corning developed the method of modified chemical vapor-phase deposition (MCVD) [4, 5, 6]. This method made it possible to obtain optical fiber with minimal losses up to ~ 0,2 dB / km at a wavelength of 1 550 nm, and in 2 002 it was possible to reduce losses to 0,148 dB / km [1, 3]. This event was the beginning of large-scale work around the world on the development of technology for the preparation and use of telecommunications optical fibers for fiber-optic information transmission systems. An optical fiber with a diameter of 125 microns without microdamage has a tensile force identical to a steel thread of the same diameter. But if there are microcracks in his body, the strength may decrease by more than 3 times [7]. To protect the optical fiber from the effects of water, various contaminants and mechanical damage to the material, an external coating is applied to its surface [8]. A primary buffer coating is formed, consisting of acrylic varnish, while the thickness of the optical fiber increases to 245 ± 10 microns [9], which makes it possible to increase its strength and protect it from the formation of microcracks, which reduce its mechanical strength [10]. The applied varnish is dried in a drying oven using ultraviolet radiation, after which the optical fiber is rolled onto coils up to 50 km in length and delivered to cable factories or to the consumer [11].

ANALYSIS OF THE PROBLEM AND THE PURPOSE OF RESEARCH

At present, the production of fiber-optic cables has been mastered in Kazakhstan, but optical fibers are imported from abroad. To organize a full cycle of production, it is necessary to set up its own production of fiber in Saran at the already operating production of fiber-optic cables. Currently, many scientific and technical problems are associated with its production, which are solved by various methods, but the main goal and task is to conduct

A. D. Mekhtiyev, e-mail: barton.kz@mail.ru, National Research Tomsk Polytechnic University, Tomsk, Russian
A. D. Mekhtiyev. S.Seifullin Kazakh Agro Technical University, Nur-Sultan, Kazakhstan
V. Yugay, E. G. Neshina, A. R. Zh. Aimagambetova V. Alkina, Karaganda Technical University, Karaganda, Kazakhstan
A. A. Kovtun, Military Engineering Institute of Radio Electronics and Communications, Almaty, Kazakhstan

scientific research related to the search for ways to increase its strength. This article studies the mechanical stresses and deformations of an optical fiber when it is stretched during the process of winding and further operation. The studies carried out allow us to solve an important production problem associated with increasing the strength of optical fiber and reducing the number of microcracks. Analysis of the literature has shown that there are a number of scientists working in this area of science. Their research reflects the urgency of the problem associated with increasing the strength of optical fiber, since it depends on the service life of the fiber-optic cable, which must be at least 20 - 25 years.

The object of scientific research is quartz optical fiber used for the production of fiber-optic cables. The production technology is already known and described earlier. To pull the fiber, the workpiece is fixed vertically in the cartridge of the exhaust system. The lower end of the workpiece is heated to a temperature of 2 000 °C and pulls the fiber down from the melting furnace. The diameter of the fiber light guide remains constant thanks to the precise adjustment of the drawing speed at 125 ± 2 microns and the drawing speed of 300 m/min. During stretching, the geometric ratios of the core glass and the shell remain unchanged; with a decrease in the diameter, the dimensions of the workpiece decrease 300 times. The refractive index profile n1 < n2 remains unchanged. Studies have shown that in the future this indicator can change under mechanical influence on the optical fiber, as well as when its temperature changes. Similar results are described in articles.

RESEARCH METHODS AND RESULTS OF LOCAL EXPERIMENTS

The strength properties of optical fibers are the most important characteristics that determine the possibility of their practical use and operation. Strength characterizes the property of materials to resist destruction under the influence of external loads. The strength measure is the ultimate strength, i.e. the maximum stress that causes the material to collapse under static load. For optical fiber, the greatest danger is represented by stretching, which is observed during fiber rewinding, during its cabling, during the laying and operation of fiber-optic cables.

Laboratory experiments conducted to study the mechanical properties of low-and zero-water peak fiber produced at the plant (ITU-T G 652D) with a diameter of 125 microns showed that when stretching segments of 1 m length, the number of samples is 50, the elongation rate is 20 mm / min, the fiber lengthens by 7 % (72 mm) in about 2 minutes. The destruction of the optical fiber occurs at a load from 44,82 to 48,08 MPa, and its elongation is about 7 %. the estimated theoretical strength of the tensile forces of quartz optical fiber was 60,00 N with a relative elongation of up to 26 %. The discrepancy between the values of the theoretical and technical strength of solids coincided with the Griffiths theory, which explains the presence of a large number of microdefects on their surface, called "Griffiths microcracks". They may be caused by the breaking of Si–O – Si chemical bonds. According to Griffiths theory, a section of optical fiber can be under load indefinitely, if the value of the applied load and the resulting mechanical stress and deformation is less than the critical value, then the fiber segment should not collapse at the time of loading. To describe the change in fiber strength under static load, the concept of inert fiber strength is introduced, provided that there are no cracks in it. But the results of practical experiments show that if a load of more than 80 % of the critical load is applied to a fiber segment, the fiber may collapse after a while. The time to failure depends on the magnitude of the applied load, the size of the defect, and the surrounding conditions. This phenomenon is related to the statistical fatigue of the optical fiber material. There are many

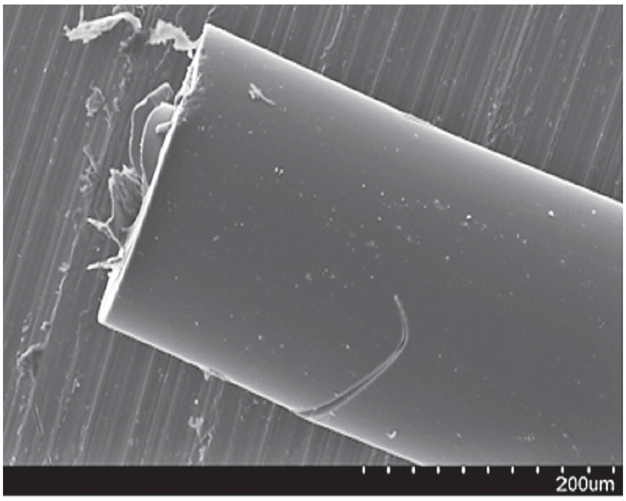

Figure 1 Photo of defects in fiber optic type G652

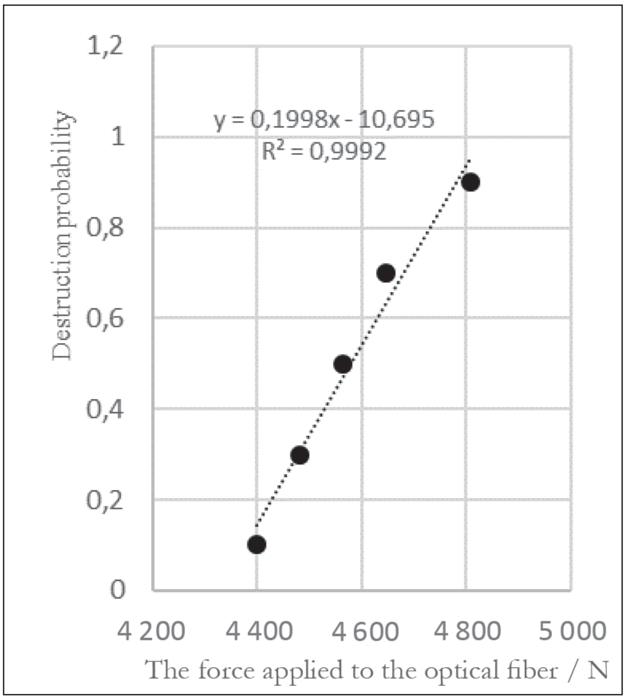

Figure 2 Dependence of the probability of failure of a G652 type fiber under tension on the applied force

defects in multi-kilometer fibers, and they change along the fiber randomly. Therefore, their influence can only be taken into account statistically, and the service life of the fiber can only be considered with a certain degree of probability.

A significant number of defects (cracks) were found along the length of the optical fiber in 50 km, which reduce its strength. Cracks are randomly distributed along the fiber. Figure 1 shows a photo of a fiber defect with a crack.

The influence of defects on the strength of an optical fiber can only be taken into account statistically; accordingly, the operating time of an optical fiber is determined with a certain degree of probability using the Weibull formula. Figure 2 shows the results of experiments to determine the strength of optical fiber.

To construct a Weibull distribution, 50 pieces of optical fiber were randomly selected and their strength was measured on a tensile testing machine. Confidence probability P = 0,95, quantile of the Student's distribution t = 2,0095 for a given confidence probability with the number of degrees of freedom n k = n - k (n k is the number of suspicious observation results). The fiber was broken in a rather narrow range from 4 482 to 4 808 MPa, the breaking strength of the fiber is influenced by the number of cracks and their parameters. Fiber optic damage occurs when an average force value of 46,04 N is applied. The absolute measurement error is ΔX = 1,96. Relative measurement error δ = 3,5 %.

COMPUTER SIMULATION OF STRETCHING OF QUARTZ OPTICAL FIBER

Modeling of the process of occurrence of mechanical stresses and deformations leading to the occurrence of cracks during stretching of an optical fiber was carried out in the ANSYS program, research methods and the obtained positive results are described in detail in [12]. The computer model was created taking into account all the technical parameters of the optical fiber and the loads of the real tearing machine used in the test. The visualization of the distribution pattern of mechanical stresses during loading of the optical fiber is shown in Figure 3.

DISCUSSION AND CONCLUSIONS

The relative elongation of the fiber is uniquely related to the amount of stress, since the quartz fiber obeys Hooke's law in a wide range of stresses up to failure. The analysis of the destruction of the optical fiber material, taking into account the cyclic load factor, showed that the main factors for the development of fatigue cracks are: the amplitude of stresses and deformations; the duration and number of loading cycles. The discrepancy between the results obtained experimentally and computer simulation of the maximum allowable load at tension was less than 15 %. Accordingly, the computer model is adequate and suitable for conducting various kinds of experiments related to the process of occurrence of mechanical stresses and deformations during stretching of a quartz optical fiber. The results of comparing the results are shown in Figure 4.

The experiments also showed that the protective polymer coating using acrylic varnish does not have a particular effect on the strength of the optical fiber, since the Young's modulus for polymer coatings is much lower than the Young's modulus for quartz glass. The coating cannot significantly increase the strength of the fiber, only within 15 - 17 %. Its functions are reduced to protecting the fiber from the external environment, abrasive particles and partially moisture. Experiments have shown that the protective coating depletes the elimination of primary defects (cracks) in the material of the primary fiber coating. The coating is capable of gluing opposite sides of microcracks and

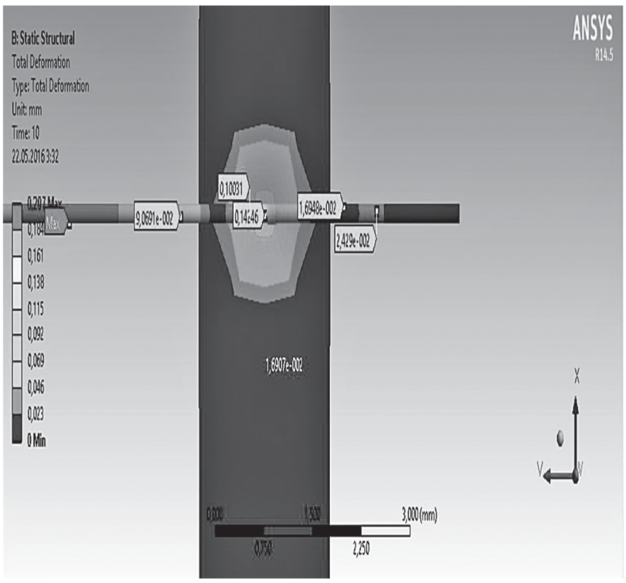

Figure 3 Computer model of G652 type fiber under tension

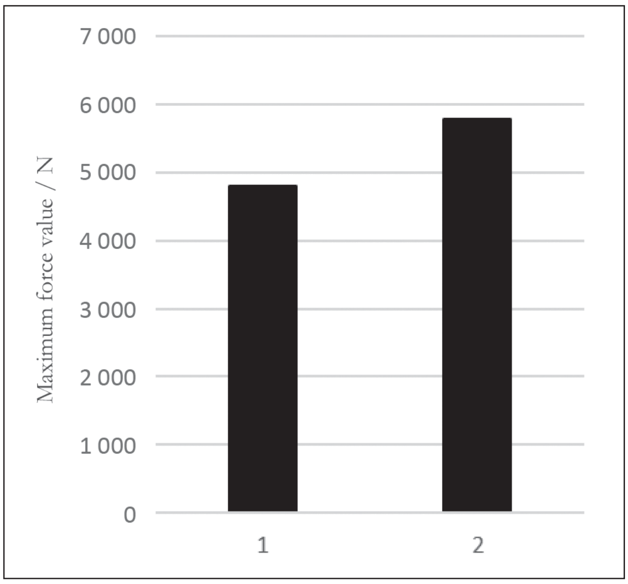

Figure 4 Comparison of results

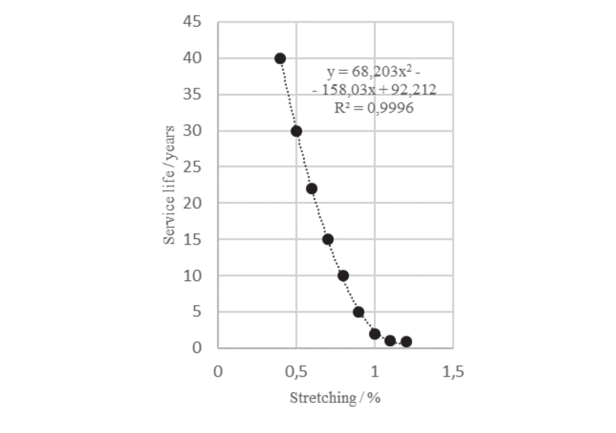

Figure 5 Dependence of the service life of an optical fiber with a change in its relative elongation in percentage

prevents them from opening. The use of a metal coating made it possible to double the maximum strength of an optical fiber in comparison with a polymer coating if doped with titanium [13]. Doped fiber optics are less susceptible to degradation and aging. It was found that the lower the rate of load growth during stretching of the fiber, the lower the value of the fiber strength. This can be explained by the fact that the fiber is under load for a longer time; accordingly, a longer time interval for crack growth is created. Figure 5 shows the dependence of the service life of an optical fiber with a change in its relative elongation in percentage. This dependence can be called dynamic fatigue. To ensure the required fiber life within 25 years, it is necessary to provide conditions under which the elongation should not exceed 0,6 %.

REFERENCES

[1] J. Wang, J. Dong. Opticalwaveguides and Integrated Optical devices for medical diagnosis, health monitoring and light therapies, Sensors 20 (2020), 3981-4014, doi:10.3390/s20143981.
[2] C. K. Kao, J. Hockham. Fiber-dielectric surface waveguides for optical frequencies, Proc. IEE 113 (1966) 7, 1151–1158. DOI : 10,1049 / piee.1966.0189.
[3] http://en.wikipedia.org/wiki
[4] W. A. Gambling. The rise and rise of optical fibers, JSTQE 6 (2000) 6, 1084 -1089, DOI: 10.1109/2944.902157.
[5] H. Roggendorf, W. Grond, M. Hurbanic. Glass Sci. Technol. 69 (1996) 7, 216 – 230,
[6] S. Nagel. An overview of the modified chemical vapor deposition (MCVD) process and performance, IEEE J. Quantum Electron.18 (1982) 4, 459 – 463.
[7] L. Skuja, M. Hirano, H. Hosono, K. Kajihara. Defects in oxide glasses, Physica Status Solidi C. 2 (2005) (1), 5–24.
[8] X. Wang, A review of the fabrication of optic fiber, Proc. SPIE 6034 (2006), 346-354. DOI: 10.1117/12.668147.
[9] A. Argyros. Microstructured polymer optical fibers. Journal of Lightwave Technology 27 (2009) 11, 1571–1579.
[10] N. Carlie, L. Petit, K. Richardon. Engineering of glasses for advanced optical fiber applications. J Eng Fiber Fabr 4 (2009) 4, 21–29
[11] V. A. Burde. Methods and means of localization of fiber defects in construction lengths of optical cable, Vestnik Svyaz, 7 (2010), 19-21.
[12] A. D. Mekhtiyev, F. N. Bulatbayev, A. V. Taranov, A. V. Bashirov, YE. G. Neshina, A. D. Alkina. Use of reinforcing elements to improve fatigue Strength of steel structures of mine hoisting Machines (MHM). Metalurgija 59 (2020) 1, 121 – 124
[13] A. Dhar. The mechanism of rare earth incorporation in solution doping process, Opt. Express 16 (2008) 17, 12835-12846.

Note: Translated from Russian into English by N. Drak, translator of Karaganda State Technical University