National Research University of Electronic Technology (MIET)
Biomedical systems Institute

The mechanical characteristics of solid and flexible structures based on single-walled carbon nanotubes and biopolymers

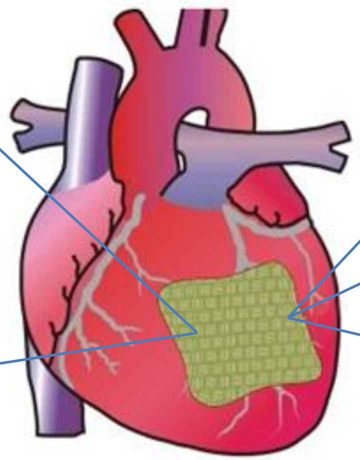
D. T. Murashko

This study was supported by the Russian Science Foundation, Project No. 20-49-04404.

Important characteristics of nanocomposite structures for cardiac tissue restoration

Porosity

Mechanical characteristics:
- Hardness
- Tensile strength
- Fatigue strength



Biodegradability

Biocompatibility

Bioactivity

Fig.1. Multilayer nanocomposite structure implanted in the area of heart miocardical infraction

Technology for the preparation of aqueous dispersions and laser formation of multilayer nanocomposite structures

Table 1. Concentration of the components used

Components	Concentration
Albumin	25 wt.%
Collagen	1 wt.%
Chitosan	2 wt.%
SWCNT	0,01 wt.%

Table 2. Geometric characteristics of nanotubes

SWCNT	Diameter, nm	Length, mkm
Small	1,4-1,6	0,3-0,8
Big	1,5-2	7-10

SWCNT – single-walled carbon nanotubes

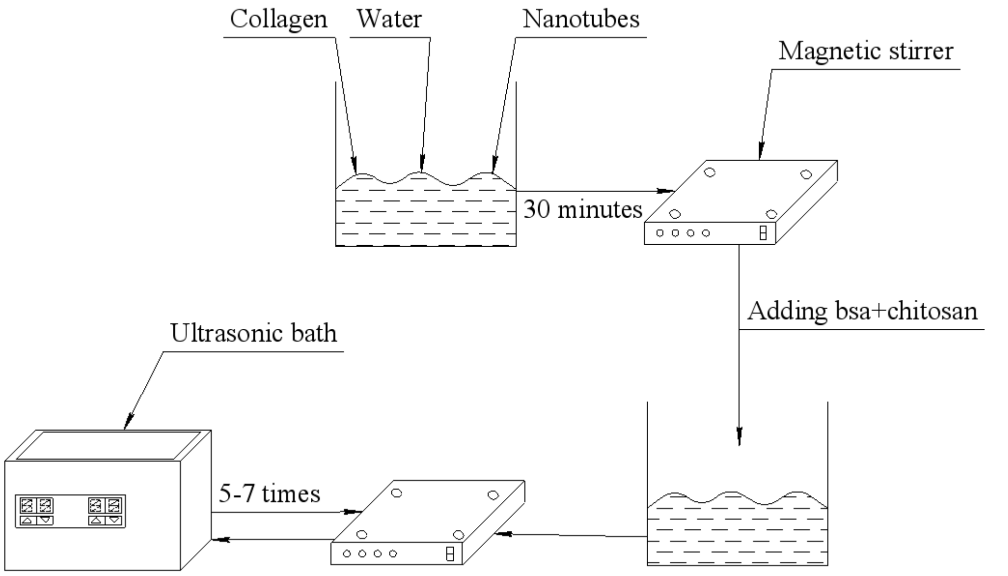


Fig.1. Dispersion preparation scheme

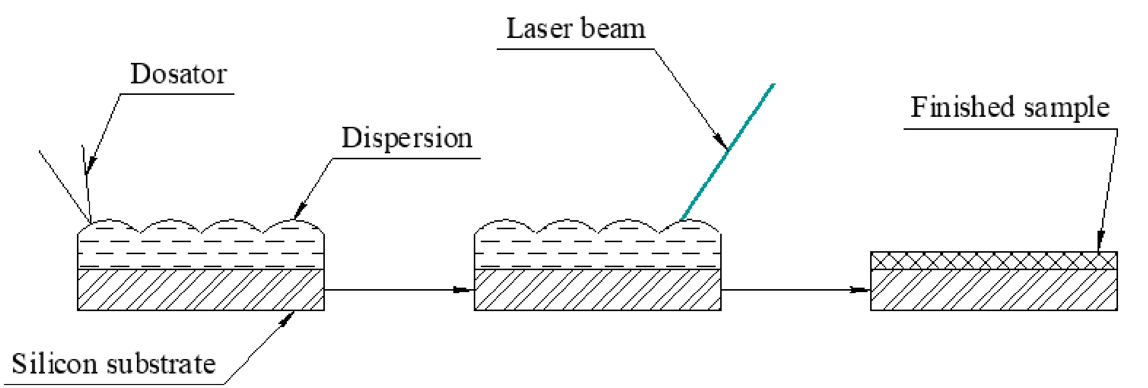


Fig.2. Scheme of laser forming of the samples of multilayer nanocomposite structures

The device for hardness measurement of multilayer nanocomposite structures

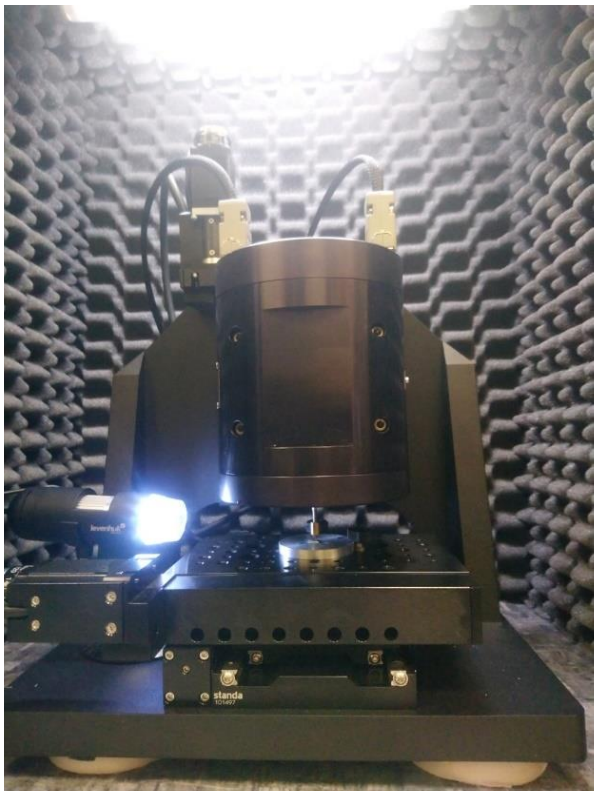


Fig.1. Nanohardness tester «NanoScan-4D Compact»

Table 1. Technical characteristics of nanoindentation module

Limiting normal load on the indenter	300 mN
Maximum load resolution	10 mkN
Limit displacement of the indenter	300 mkm
Maximum travel resolution	0,3 nm

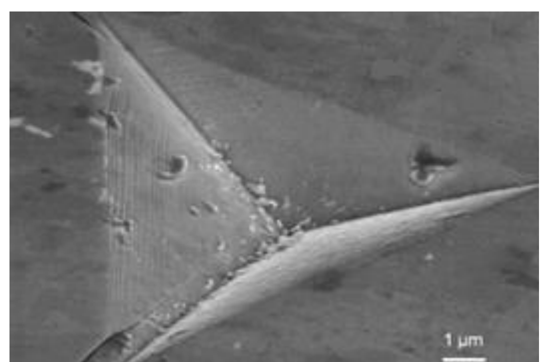


Fig.2. Image of a print in the material from indentation by the Berckovich indenter

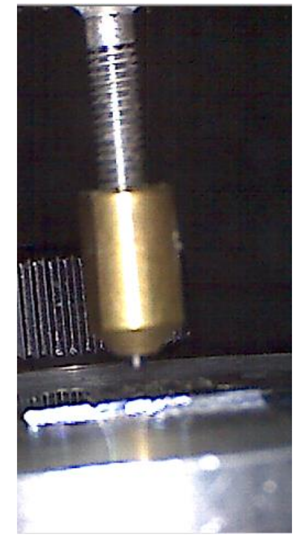


Fig.3. Process of hardness measurement by pressing the indenter into the material

Hardness measurement results of multilayer nanocomposite structures

Sample composition		Hardness, GPa
Biopolymer concentration	Concentration and SWCNT type	
Albumin (25 wt.%)	Small SWCNT (0,01 wt.%)	0,26±0,08
Collagen (1 wt.%)	Small SWCNT (0,01 wt.%)	1,10±0,76
Chitosan (2 wt.%)	Small SWCNT (0,01 wt.%)	3,30±1,08
Albumin (25 wt.%), Collagen (1 wt.%), Chitosan (2 wt.%)	Small SWCNT (0,01 wt.%)	0,22±0,08
Albumin (25 wt.%) Collagen (1 wt.%) Chitosan (2 wt.%)	Big SWCNT (0,001 wt.%)	0,07±0,04
Albumin (25 wt.%) Collagen (1 wt.%) Chitosan (2 wt.%)	Big SWCNT (0,01 wt.%)	0,19±0,07
Albumin (25 wt.%) Collagen (1 wt.%) Chitosan (2 wt.%)	Small SWCNT (0,001 wt.%)	0,19±0,04

Hardness maps distribution in the layers of multilayer nanocomposite structures with small SWCNT

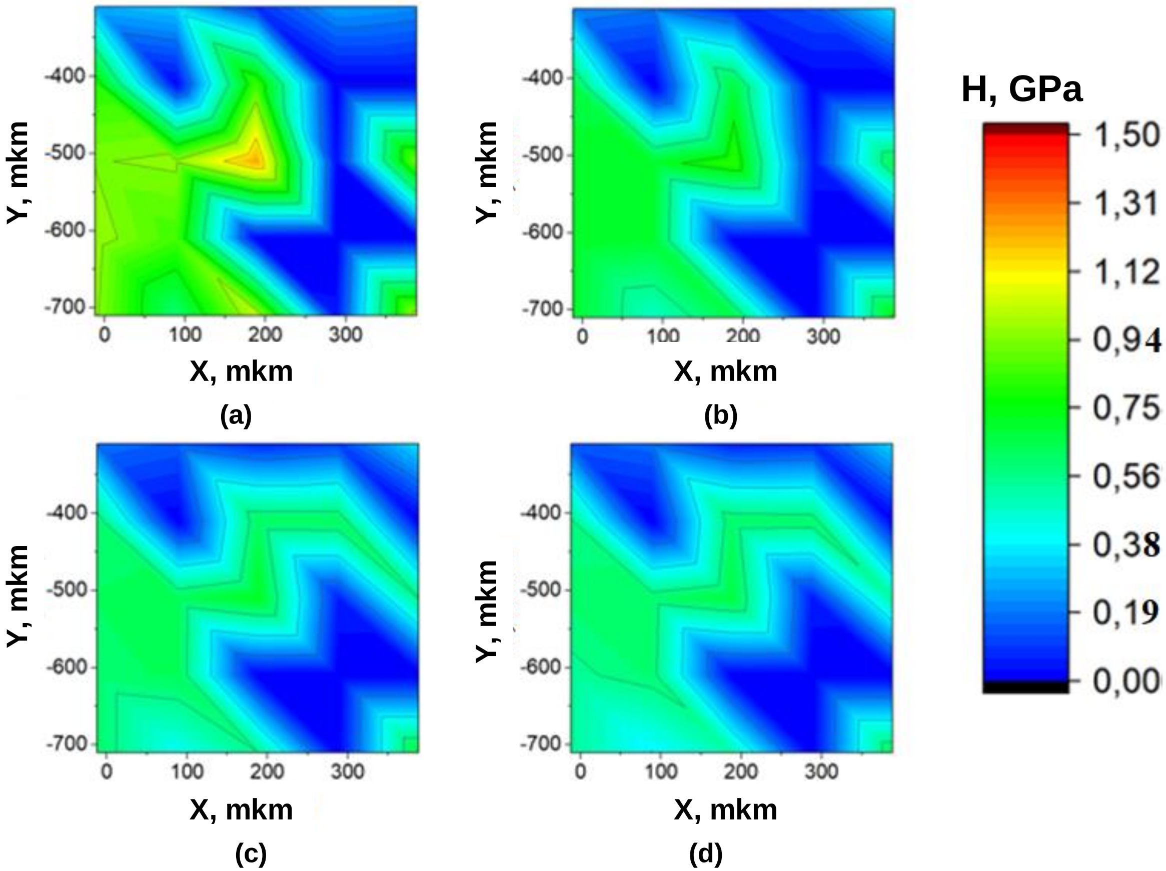


Fig.1. Hardness maps distribution at different depths: (a) 200 nm, (b) 400 nm, (c) 600 nm, (d) 800 nm

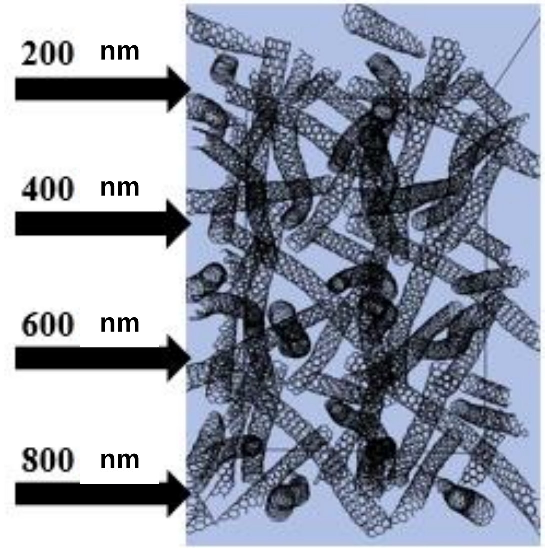


Fig.2. Depths of hardness measurement

Table 1. Hardness analysis

Minimal Hardness, GPa	0,050
Maximal hardness, GPa	1,313
Average hardness, GPa	0,750
Depth with maximal hardness, nm	200

Hardness maps distribution in the layers of multilayer nanocomposite structures with big SWCNT

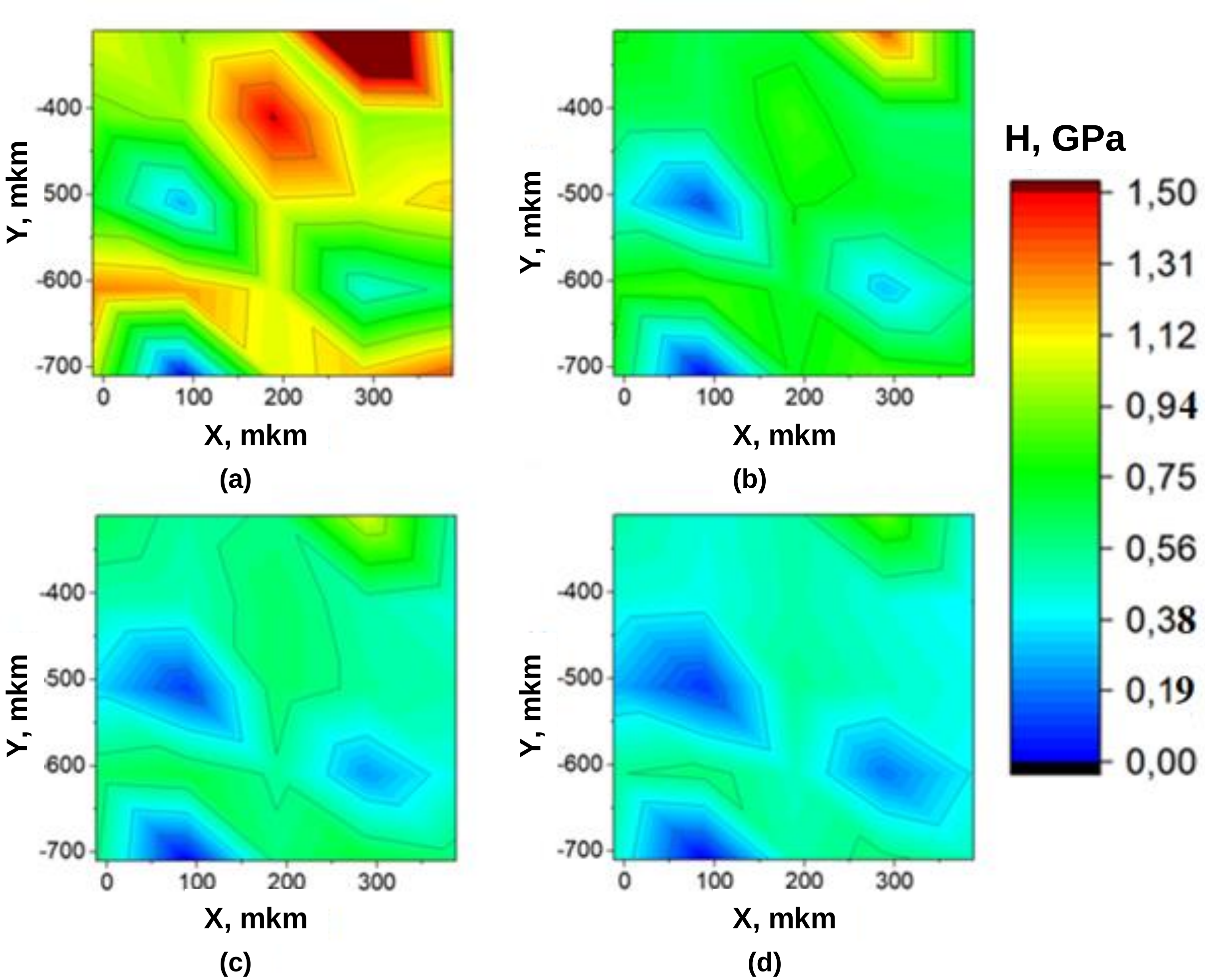


Fig.1. Hardness maps distribution at different depths: (a) 200 nm, (b) 400 nm, (c) 600 nm, (d) 800 nm

Table 1. Hardness analysis

Minimal Hardness, GPa	0,185
Maximal hardness, GPa	1,500
Average hardness, GPa	0,750
Depth with maximal hardness, nm	200

Stands for the study of fatigue strength of multilayer nanocomposite structures

Fig.1. Device for low-cycle loads

Fig.3. Device for multi-cycle loads Instron Electropuls E3000

Table 1. Cyclic test conditions

The number of tensile compression cycles at low-cycle loads	100
Velocity of tensile compression	10 mm/s
The number of tensile compression cycles at multi-cycle loads	2592000
Velocity of tensile compression	88,2 mm/s

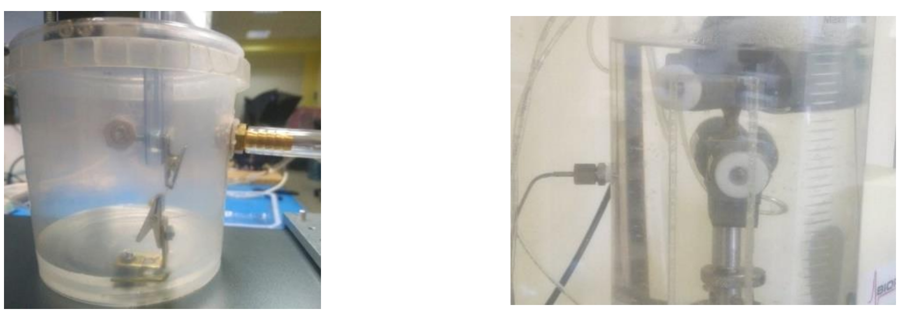


Fig.2. Process of sample testing in physiological environment at a temperature 37ºC

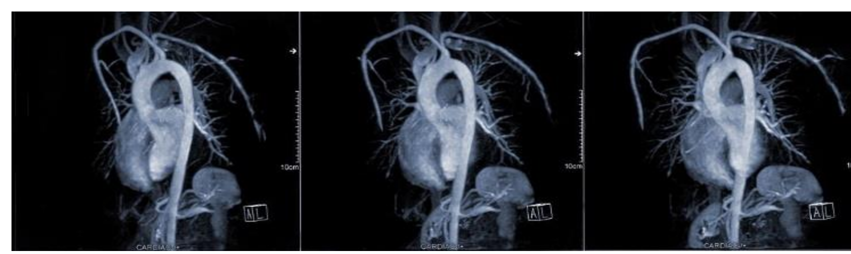


Fig.4. Tomogram of the heart

Fatigue strength of multilayer nanocomposite structures during low-cycle loads

Composition of samples	Tensile distance, mm	Applied force F, N	Cross-sectional area S, mm^2	Nominal tension σ_N, MPa
Albumin (25 wt.%) Collagen (1 wt.%) Chitosan (2 wt.%) Small SWCNT (0,001 wt.%)	No tensile	9,8±0,1	2±0,4	4,9±0,8
	10	9,7±0,1	1,0±0,2	9,7±1,6
	15	7,3±0,1	0,75±0,15	9,7±1,6
	20	9,5±0,1	1,5±0,3	6,3+1
Albumin (25 wt.%) Collagen (1 wt.%) Chitosan (2 wt.%) Small SWCNT (0,01 wt.%)	No tensile	9,9±0,1	1,0±0,2	9,9±1,6
	10	5,0±0,1	1,0±0,2	5±0,8
	15	8,4±0,1	1,0±0,2	8,4±1,4
	20	5,3±0,1	1,0±0,2	5,3±0,9

Tensile strength of multilayer nanocomposite structures and control sample

Таблица.1. Strength limits of experimental samples and cardiac tissues

Type of samples	Cross-sectional area S, mm^2	Maximal load, N	Tensile strength, MPa
Control sample (classic implant for cardiac tissue restoration without cyclic loads)	12±0,1	77,0±0,4	6,9±0,5
Multi-layer nanocomposite structure (after multi-cyclic loads)	12±0,1	20,0±0,1	1,6±0,1
Tensile strength of left ventricular myocardium of man at age from 31 to 40, MPa	2,1- 3,1		
Tensile strength of anterior wall of the aorta, MPa	1,1		

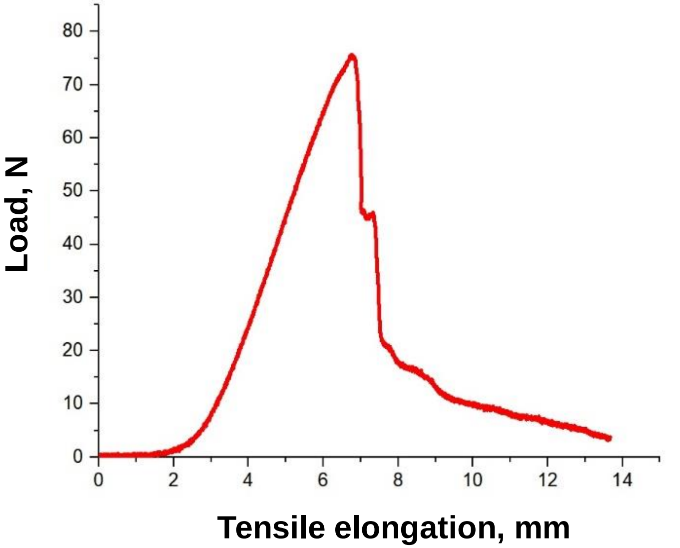


Рис.1. Diagram of the rupture process of the control sample

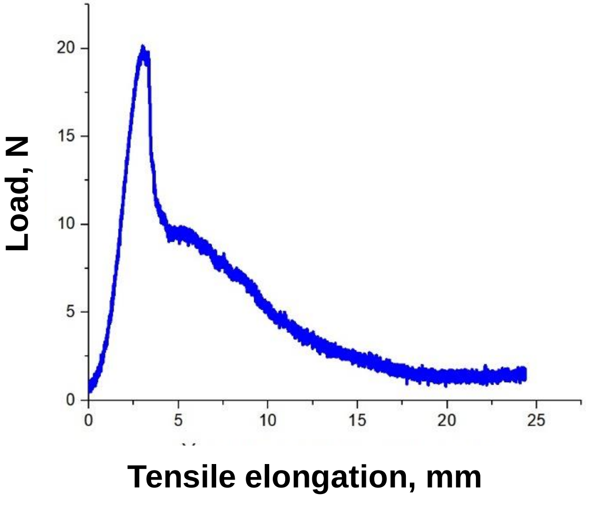


Рис.2. Diagram of the rupture process of the sample of multilayer nanocomposite structure

Results

- A method has been developed for the preparation of samples of multilayer nanocomposite structures for the restoration of heart tissues from layers of biopolymers (albumin, collagen, chitosan) with small and large single-walled carbon nanotubes.
- Measurements of the hardness of multilayer nanocomposite structures for the restoration of heart tissue have been carried out. Maps of hardness distribution of various layers of nanocomposite structures at depths of 200, 400, 600, and 800 nm from the surface were created. It was found that the maximum hardness inherent in the near-surface layer of structures with large nanotubes at a depth of 200 nm was 1.5 GPa.
- Stands have been developed for the study of tensile strength after low- and many-cycle loads (fatigue strength), simulating cardiac muscle contractions.
- Measurements of the fatigue strength of multilayer nanocomposite structures under low- and high-cycle loads made it possible to prove their applicability for the restoration of defects in cardiac tissue. After simulating heart contractions for 2 months in a physiological environment at a temperature of 37 ° C, the tensile strength was 1.6 ± 0.1 MPa.

National Research University of Electronic Technology
(MIET)
Biomedical systems Institute

Thank you for attention!

This study was supported by the Russian Science Foundation, Project No. 20-49-04404.