UDK 539.23; 539.32

MECHANICAL PROPERTIES AND ACOUSTIC PARAMETERS TUBES OF ZIRCONIUM ALLOY Zr1%Nb WITH A PROTECTIVE COATINGS

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Research results of influence of various coatings deposited by ion-plasma method on the mechanical properties and acoustic parameters of the samples from the fuel tubes made of Zr1%Nb alloy are presented. Ring samples were tested in tension at room temperature in the radial direction. It is shown that the coatings have a significant influence on strength and plastic characteristics of the samples. Thus, the ultimate strength of the samples with coatings 18Cr10NiTi, Cr/CrN, TiN increases from 15.5 to 16.5%, and the yield strength from 8 to 12.5%. The preservation of plasticity (or slight increase) was detected for coatings CrAl; CrAl/CrN and ZrN. The best combination of mechanical properties have samples with coatings CrAl; CrAl/CrN and 18Cr10NiTi. The conclusion about the functional state of a protective coating in the field of elastic and plastic deformation is made by means of an amplitude analysis of acoustic emission signals recorded during mechanical tests.

INTRODUCTION

Zirconium alloys are the main structural material for products active zones of nuclear power reactors (fuel cladding, distanciruemsa gratings, etc) [1–2]. The most critical components of the fuel element shell tubes is. Fuel cladding work in difficult conditions of temperature, radiation exposure, stress, corrosion factors and hydrogen saturation. In addition, the surface of the tubes can be damaged as at the time of installation of assemblies and in operation. All these factors significantly affect the degradation of the mechanical properties of the material and reducing the duration of the resource of its operation [3–7].

There are two ways to increase the service life of zirconium products:

– development of new alloys with perfect microstructure and a high level of physical and mechanical properties;

– development of new technological processes of processing of products from existing alloys, primarily based on the modification of the structural state and properties of surfaces and applying variety of protective coatings.

The creation of new alloys is the lengthy and expensive process that requires considerable financial costs and time on complex testing and research. Economically, therefore, seems more appropriate the second way consists in increasing the performance properties of zirconium products and their protection from corrosion and hydrogenation using surface modification or creation of thin surface layers, differing in composition, structure and properties from the base alloy from which they are made.

Such coatings must solve the problem of corrosion, hydrogenation and increase the mechanical characteristics of zirconium products. Surface modification is carried out by ion-plasma deposition of metals and ion implantation [8, 9], plasma processing, laser, electron and ion beams [10].

The pulsed electron beam (PEB) allows radically modifying surface layers with thickness of tens of micrometers, virtually without changing the structural-phase state of the main volume of the product. The efficacy of using the PEB to improve the mechanical properties (increase of hardness, improve corrosion resistance and wear resistance, reduce friction coefficient) of structural materials has been demonstrated in [8–10].

In NSC KIPT in the last 40 years, research into building high performance and effective methods for surface modification of constructional materials, efficiency and high level of which the Institute retains a leading role in the field of vacuum-arc coatings. These investigations allowed to create the industrial method of applying various coatings and to develop the equipment (with different performance characteristics) for its implementation, which are widely used in many industries of various countries to create effective functional coatings [11–13].

When developing coatings on tube of fuel in the first place it is necessary to control the mechanical characteristics of specimens with coatings and mechanical behavior (integrity) of the coating in the operating stress range, i.e. below the yield stress. Information on this behavior can be obtained as a result of research of acoustic emission that occurs during deformation of the samples.

The aim of this work was to study the mechanical characteristics and acoustic parameters tensile specimens from tubes of fuel made from alloy Zr1%Nb with different coatings.

RESEARCH METHODOLOGY

The specific geometry and dimensions of products made of zirconium alloys used in nuclear installations, in most cases does not allow to produce standard samples and apply the methods stipulated by the state standards for other industries. In this regard, the practice is widely used special methods of mechanical testing that are tailored to specific sizes of products adequately and allowed to characterize the mechanical characteristics of the material.

In this work, test specimens were cut mechanically from tubes of fuel, which were manufactured in Dnepropetrovsk from zirconium alloy Zr1%Nb of Ukrainian production. Mechanical properties of thin-walled tubes in the transverse direction are usually determined as a result of tests of ring specimens for tensile rupture on semi-circular supports. The calculations of the parameters for samples of zirconium materials taking into account the uneven braking deformation at the supports, has allowed for testing in this work, we use samples of size 13,1×0,65×2.8 mm. The appearance the ring samples and device for its tests is shown in Fig 1.

Fig.1. The appearance of ring specimen and fixture for testing

The deposition was carried out by the vacuum - arc method on the setting “Bulat”" using cathodes of Zr, Cr, Al, Ti, Cr18Ni10Ti [9]. The coating of samples have different amounts of layers and components. The multilayer coating was performed based on alternating layers of pure metals and their nitrides. The temperature of samples in the condensing mode was approximately 400 °C. The vacuum arc currents varied between 80...100 A. The pressure of the reaction nitrogen gas was 0.4...0.6 Pa.

The tensile samples in the radial direction was performed on a universal testing machine 1958 U10-1 with a strain rate of 0.17 mm/min ($2 \cdot 10^{-4}$ c^{-1}) at room temperature. The obtained curves were determined tensile strength, yield strength and elongation. Synchronously with the mechanical characteristics by acoustic complex M400 recorded parameters of acoustic emission (activity, total amount of pulses, amplitude, etc.), the analysis of which allowed to determine the peculiarities of deformation of the sample material and the coatings at different stages of deformation and acoustic amplitude distribution of AE signals allowed to estimate the energy of the moment of deformation. As the sensor-recorder AE used a piezoceramic transducer from ceramics PZT-19 with resonant frequency of 180 kHz. The sensor is fastened to the tested sample through a special waveguide, which served as one of the fastening supports of the specimen in the fixture for testing. The collection, processing and analysis of the results, including information about acoustic emission parameters and the deformation, was performed using computers and specially developed data processing programs.

RESULTS AND DISCUSSION

The mechanical characteristics of the samples tested in the initial state, i.e. without coatings and with deposited coatings of various thicknesses are given in Table.

Mechanical characteristics of samples with different coatings

No	Coating// thickness //treatment	σ_B, MPa	σ_T, MPa	extension, mm
1	Initial state	434.2	372.6	2.00
2	TiN //10.0 μm	505.7	419.2	1.68
3	TiN //13.0 μm	466.0	386.0	1.50
4	ZrN // 2.5 μm	462.7	379.8	1.76
5	ZrN //2. μm //vac.ann. 550 °C, 1 h	417.5	339.5	2.05
6	ZrN //6.0 μm	444.30	375.0	1.60
7	ZrN //6.0 μm // vac.ann. 550 °C, 1 h	430.3	354.3	1.82
8	ZrN //11.0 μm	474.2	405.4	1.82
9	Zr(ON) //4.0 μm	474.8	405.0	1.80
10	CrAl // 5.0 μm	473.0	388.5	2.30
11	18Cr10NiTi //10.0 μm	496.4	409.2	1.90
12	CrAl/CrN //8.5 μm	479.5	410.0	2.03
13	Cr/CrN //14.0 μm	472.9	374.7	1.00
14	Cr/CrN //14 μm // vac.ann. 550 °C, 1 h	505.4	402.7	1.15
15	ZrCr/Cr/CrN //9.0 μm	490.7	398.4	1.43

Consider the features of the behavior of mechanical and acoustic parameters during deformation of the samples from source tubes and tubes with different coatings.

Original tube and coated TiN and ZrN. In Fig. 2 shows the dependence of the stress and activity from AE time of loading (i. e., the magnitude of the deformation), as well as the amplitude distribution for the original (uncoated) of the sample is cut mechanically from tube of fuel. The Y axis of the histogram amplitude distribution pending the number of AE signals (in relative terms), which registered each peak counter configured for a certain interval of amplitudes, in the testing process.

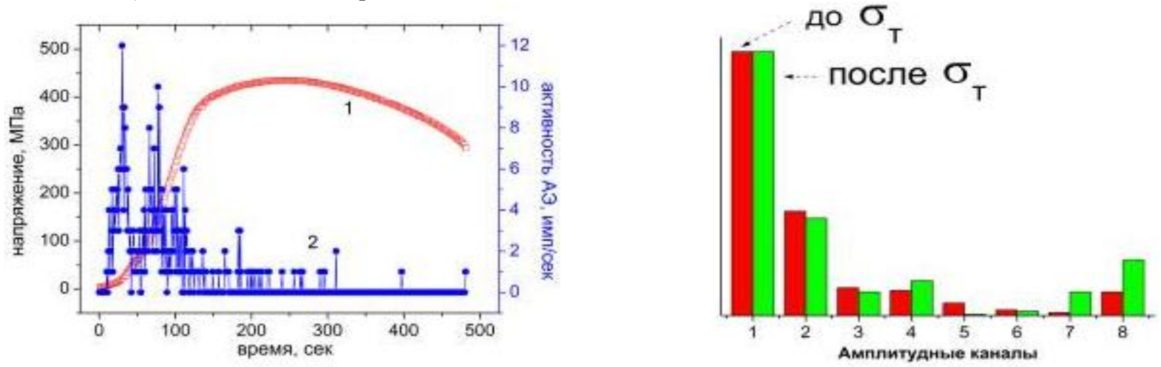

Fig. 2. The dependence of stress (1), the activity of AE (2) from the loading time of the original (uncoated) sample and the amplitude distribution of AE signals during the deformation of samples in the stress range before and after the yield point

The curve "stress-deformation time" (curve 1, Fig. 1,a) represents a typical curve of plastic deformation of the sample.

Acoustic emission starts to register immediately after the start of deformation of the sample (in the field stresses below the yield strength of the material). The absolute value of AE in this area is low (~10 pulse/s), and further increase load in the area of plastic flow AE almost vanishes (~ 1…2 pulses/s). The maximum number of AE is observed at stresses much smaller yield stress. We assume that the AE in this area stresses associated with friction processes at the border "pipe–clamps". Confirmation of this assumption is a practical absence of acoustic emission in testing samples in compression.

Amplitude distribution of signals generated in the stress range below (left column) and higher yield stress (right column), several more almost equally high amplitude signals (right columns of channels 7 and 8) in the area of plastic flow. It is probably connected with the initiation and propagation of cracks before the destruction.

One of the most common types of wear-resistant coatings is of significant interest for engineering, electronics and microelectronics are coatings based on titanium nitride. Wide use of hard wear-resistant coatings on steel machine parts, including compressor, for cutting tools, diffusion barriers in electronics, decorative and corrosion resistant coatings, etc. is because the titanium nitride has a high hardness, wear resistance and elastic modulus, and chemical stability.

In Figs. 3 and 4 shows the changes in mechanical and acoustic parameters of the samples with applied ion-plasma method by coating titanium nitride (TiN) with a thickness of 10 and 13 µm. during the deformation.

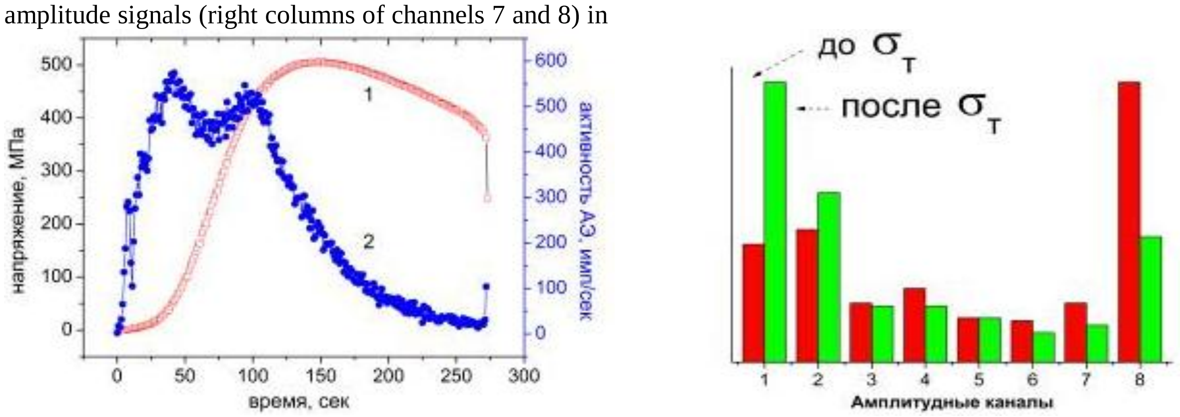

Fig. 3. The dependence of stress (1), the activity AE (2) from the loading time of the sample with the coating (inner and outer surfaces) 10 μm TiN and the amplitude distribution of AE signals during the deformation of samples in the stress range before and after the yield point

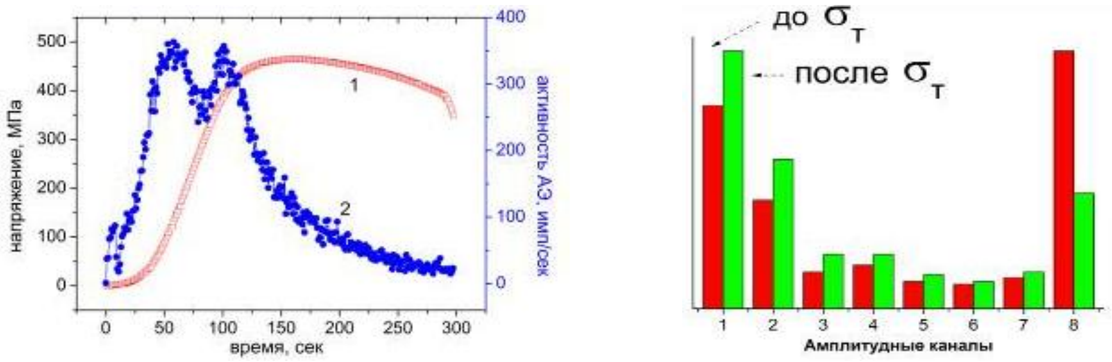

Fig. 4. The dependence of stress (1), the activityAE (2) from the loading time of the sample with the coating (outer surface) TiN 13 μm and the amplitude distribution of AE signals during the deformation of samples in the stress range before and after the yield point

From Figs. 3 and 4 shows that the activity of AE in samples with coating TiN is much higher than the original sample. The samples of zirconium with TiN coating AE begins well before reaching the stress corresponding to their yield stress. The amplitude distribution analysis showed that during the deformation in the area of stresses to yield stress in the spectrum of AE signals dominated by high amplitude signals. Their contribution to the activity of the AE integral with a further deformation decreases. Compared to the starting material the coated samples have higher values of tensile strength and ductility. TiN coating resulted to a reduction in the elongation of the samples (see tab.1).

The coating thickness of 10 microns was coated on inner surfaces of the tubular sample. It was interesting to compare the mechanical and acoustic parameters when coating only on the outer surface of the sample. Tested samples were coated with a TiN film of a thickness of 13 µm on the outer surface. The nature of changes in stress and activity of AE in samples with coating thickness of 10 µm and 13 were similar, but samples with coating on the outside of the AE activity is lower than that of the sample with double-sided coating of the TiN. From the graph, amplitude distribution shows that at the initial phase of deformation (up to yield stress) of this sample have registered a few more low-amplitude signals.

For many years in various industries widely used a coating of zirconium nitride (ZrN). This coating has an excellent combination of erosion resistance, coefficient of friction and plasticity. In Fig. 5–7 show the dependences of mechanical and acoustic parameters of the samples, with applied ion-plasma method by coating of zirconium nitride of a thickness of 2,5, 3,0 and 6,0 µm after coating and after annealing in vacuum at a temperature of 550 °C for 1 hour.

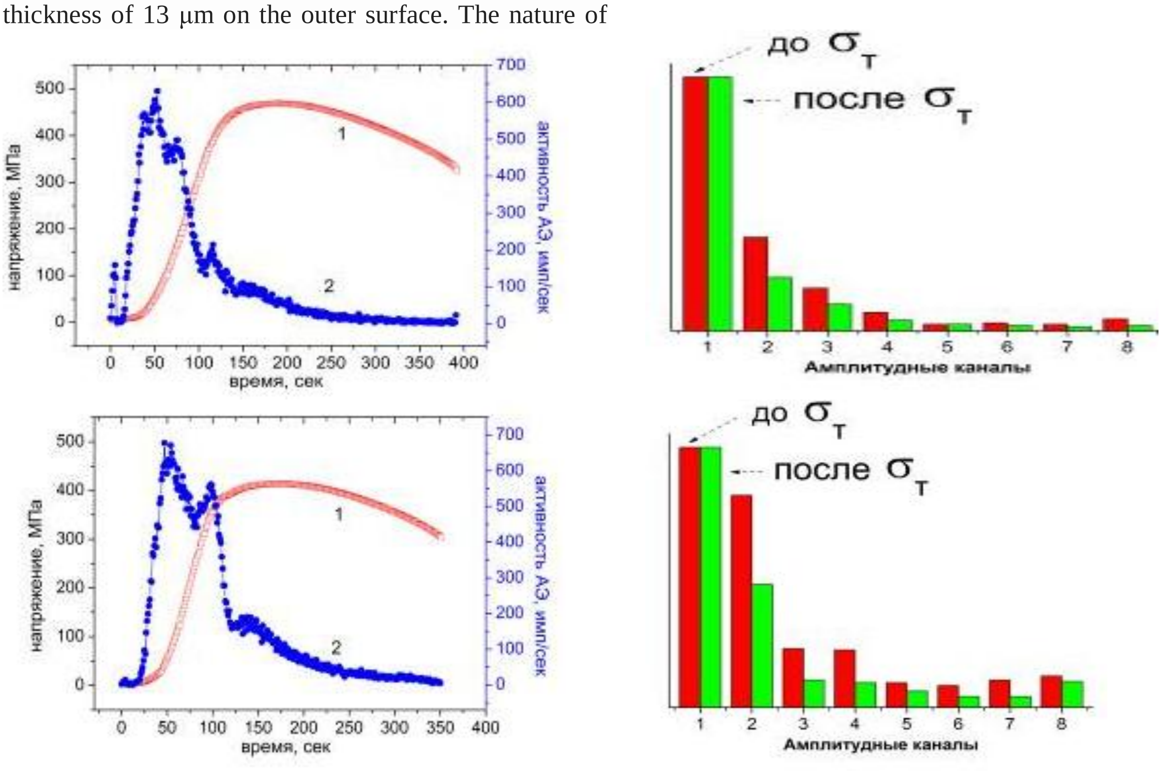

Fig. 5.The dependence of mechanical (1), acoustic parameters (2) from the loading time and the amplitude distribution of acoustic emission signals from samples zirconium nitride coating thickness of 2.5 μm after plating and after annealing in vacuum at 550 °C 1 hour

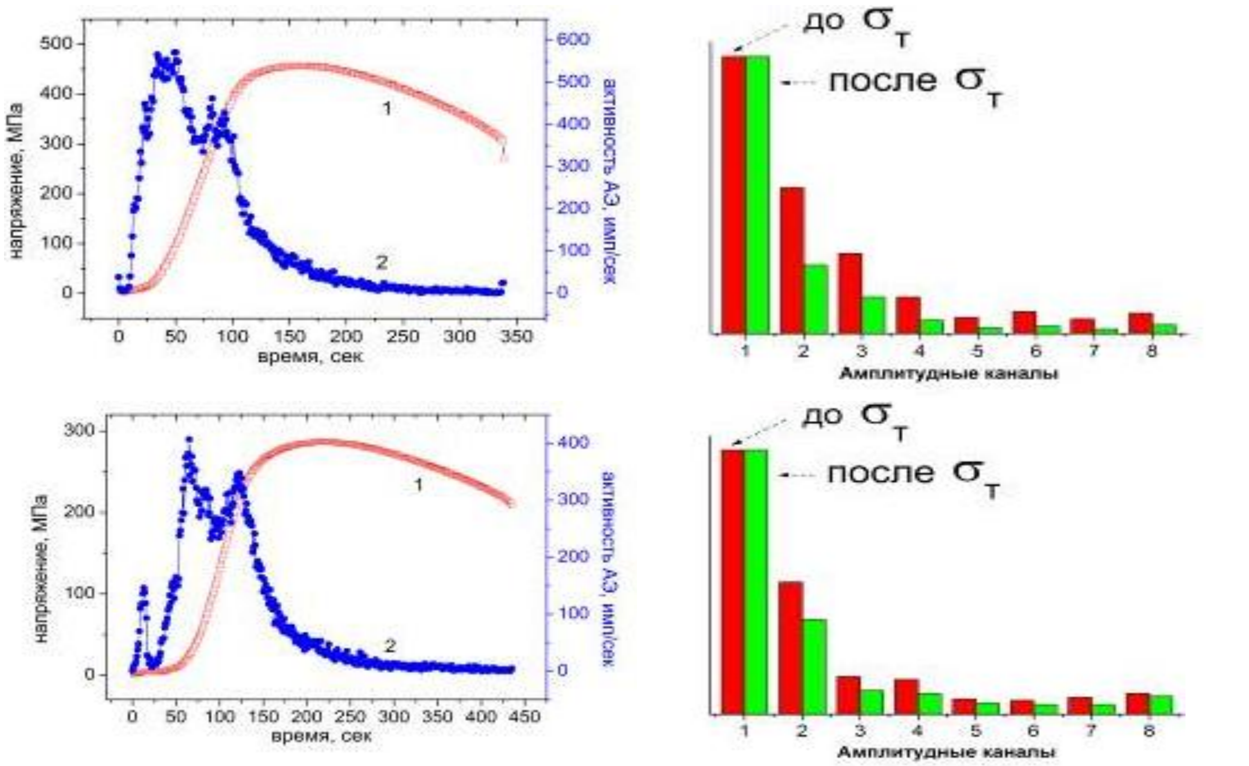

Fig. 6. The dependence of mechanical (1) acoustic parameters (2) from the loading time and the amplitude distribution of acoustic emission signals from samples zirconium nitride coating thickness of 3.0 μm s after plating and after annealing in vacuum at 550 °C 1 hour

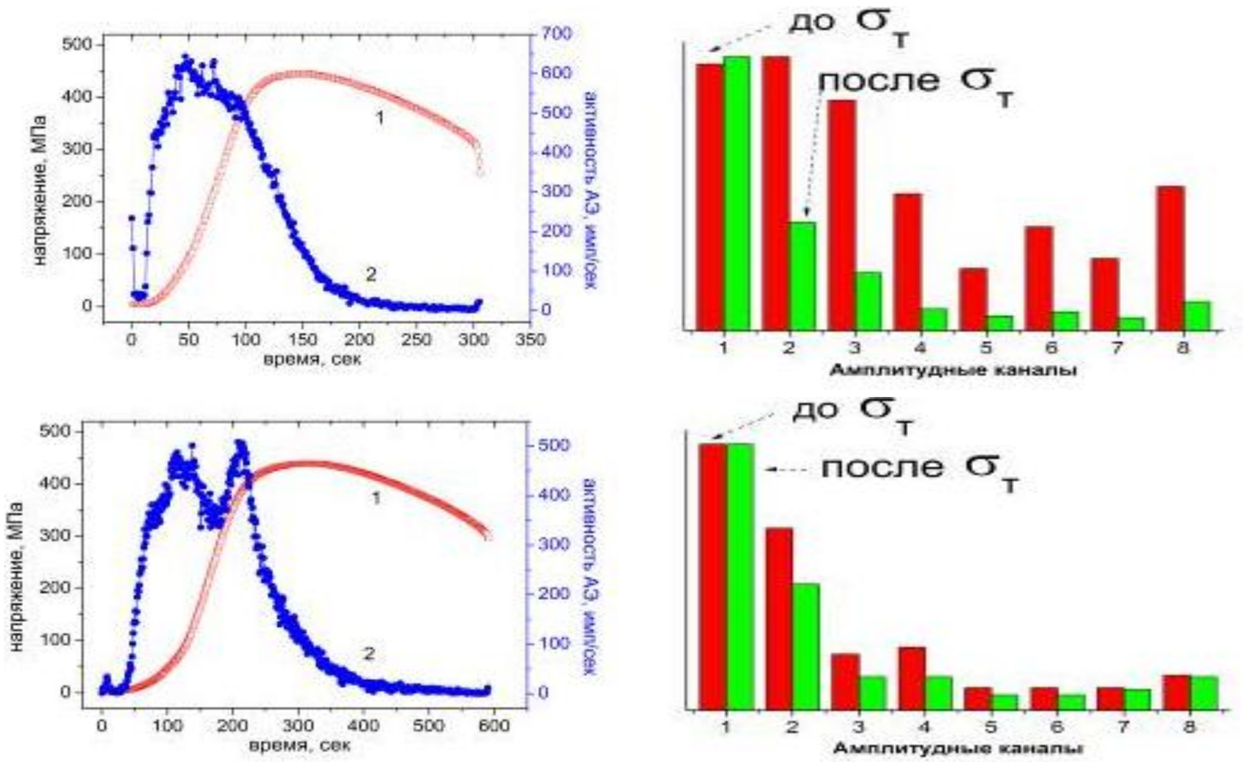

Fig. 7. The dependence mechanical (1), acoustic parameters (2) from the loading time and the amplitude distribution of acoustic emission signals from samples zirconium nitride coating thickness of 6.0 μm after plating and after annealing in vacuum at 550 °C 1 hour

From the data analysis tab.1 that with the increase of the thickness of the ZrN coating decreases the tensile strength, the yield strength is almost constant, decreases the elongation of the sample. You should note that the ZrN coating as the TiN coating reduces the elongation of the sample compared with the state of the sample without coating. Annealing at 550 °C reduces the tensile strength and yield strength increases and the elongation of the sample to values close to the elongation of the samples in the initial state.

From Fig. 5–7 shows that, compared with the initial state of the samples with the coating increases the activity of the AE. The absolute value of AE is approximately the same as that of the samples with TiN coating. Registration of AE signals starts immediately after the start of deformation and the curve of all peaks of activity occur in the area of stresses below the yield stress. You should pay attention to the following features of the dependence of the activity AE:

– the first peak of AE curve is observed at approximately the same stress is below the yield strength (~0.25 σ_T), and when stresses equal to the yield strength of the absolute activity values increased with increasing coating thickness (trailing edge of AE curve shifts right with increase in the thickness of the coating);

– annealing at 550 °C for one hour also shift the trailing edge of the activity curve to higher stresses and leads to a clearer manifestation of the second peak on the curve the activity of AE.

With increasing thickness of the ZrN coating is not very much change in the dependence of the average amplitude of AE pulses from movement of the grippers. The trend of growth of the sum of AE pulses with increasing coating thickness. The analysis of the distribution of the AE pulses of amplitudes showed that the increase in the number of pulses occurs approximately equally across all channels. Slightly different amplitude distribution of AE signals from specimens with a coating thickness of 6 μm.

Interesting, in our opinion the result is shown in Fig. 8, which refers to the sample with ZrN coating thickness of 11 μm. This coating was applied to another setting, but with close parameters of the coating process on first install. From Fig. 5–7 and Fig. 8 shows that the main features of the curves of mechanical and acoustic parameters is maintained. Comparing amplitude distribution Fig. 5–6 and Fig. 7–8, we can assume that there exists a boundary film thickness, below which we have an exponential decrease in the number of signals with increasing amplitude (amplitudes distribution corresponding to the viscous destruction). Above this border species distribution changes significantly and there is an amplification of the differences in amplitude distribution of AE signals during deformation in region of the stress before and after the yield point.

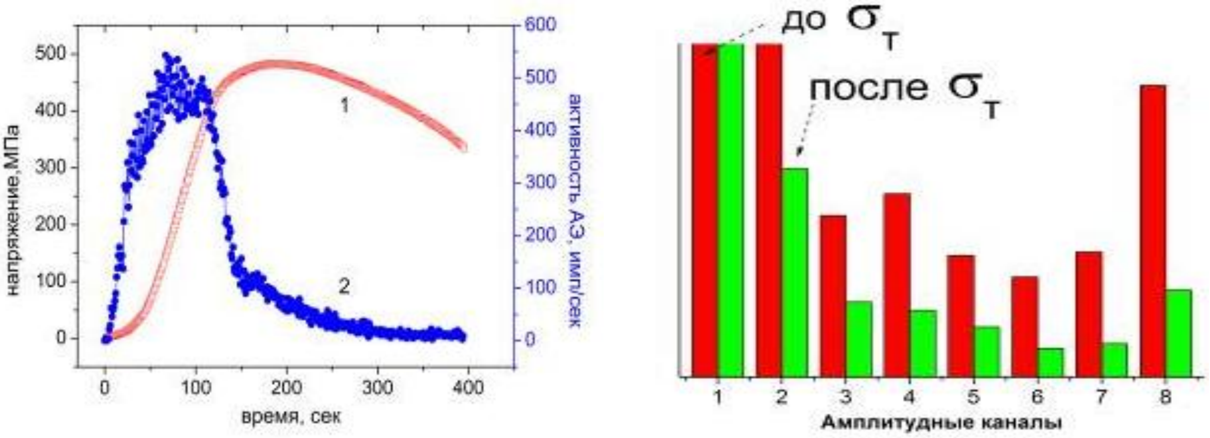

Fig. 8. The dependence of mechanical (1), the acoustic parameters (2) from the loading time and the amplitude distribution of AE signals samples with zirconium nitride coating thickness of 11.0 μm

ZrON Coating. In industry the coating is used for corrosion and erosion protection products. In Fig. 9 shows the dependence of strain and AE activity for samples with coating thickness of ZrON 4 μm (external side) and the distribution of AE signals at the amplitude levels in the deformation area in the stress up to yield point and after.

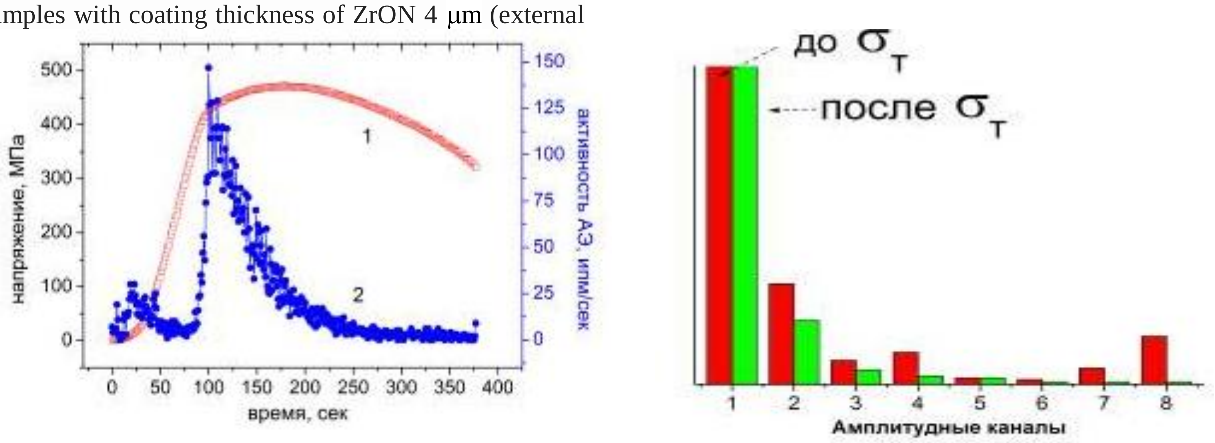

Fig. 9. The dependence of mechanical (1), the acoustic parameters (2) from the loading time and the amplitude distribution of AE signals of samples with coating thickness of 4.0 μm ZrON

The ZrON coating thickness of 4 μm leads to an increase in the tensile strength and yield strength and decrease of elongation of the sample compared with the initial state. From Fig. 9 shows that the AE signals in the initial stage of loading small and surge starts when approaching the yield stress. Peak activity of AE curve lies in the region of yield strength. The amplitude distribution analysis showed that in the spectrum of AE signals (especially in the area of stress above the yield limit) is dominated by low-amplitude signals. That is, the deformation of the sample is low-energy processes, most likely a dislocation. And the view of amplitude distribution of AE signals similar to the distribution in the viscous destruction of the material.

Coating of CrAl alloy. The coating CrAl as ZrON coating increases wear-resisting properties tool and product on which it is applied. In addition CrAl coating increases the thermal stability of the products. In Fig. 10 shows the dependence of the stress and activity from AE time of loading for samples with CrAl coating thickness of 5 μm (from the outside) and the distribution of AE signals at the amplitude levels in the deformation area in the stress up to yield point and after.

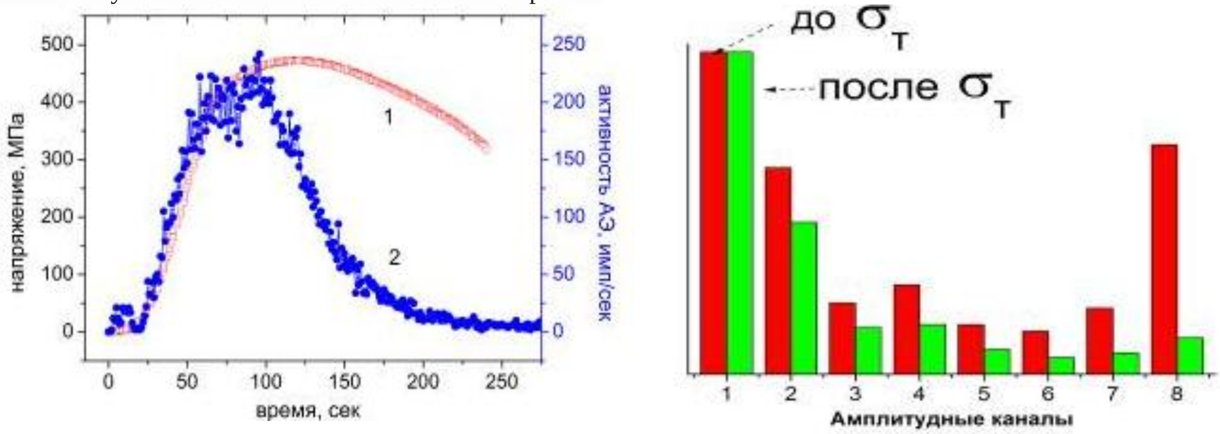

Fig. 10. The dependence of the stress (1) and AE activity (2) samples of coated CrAl (from the outside) with a thickness of 5 μm and the distribution of the AE signals from the amplitude levels during deformation in area stress before and after the yield point

On this cover you must pay attention, because applying it to the sample leads to a small increase in the tensile strength and yield strength and a pronounced increase in elongation (compared to the samples without coating). From Fig. 10 shows that the AE begins to register at the initial stage of deformation increases in proportion to the applied voltage. Peak activity of AE curve lies in the region of yield strength. The decrease of the absolute values of AE occurs in the zone of plastic flow. There is a significant difference in amplitude distribution of AE signals during deformation of the sample in the elastic and plastic zone.

The stainless steel cover. Such coatings are commonly used for corrosion protection of metal equipment. In Fig. 11 shows the dependence of strain and AE activity for samples with a coating of stainless steel with a thickness of 10 μm (from the outside) from the time of deformation.

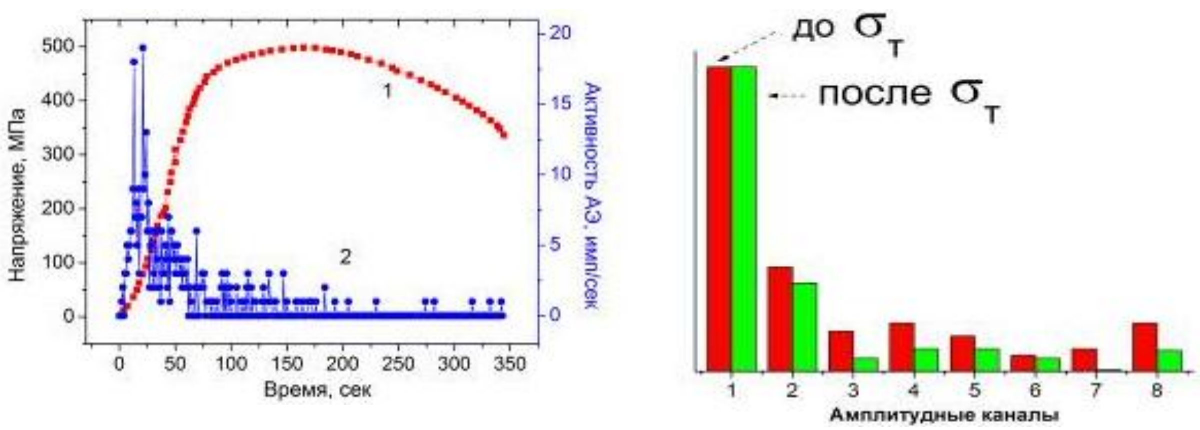

Fig 11. The dependence of the stress (1) and AE activity (2) samples of coated stainless steel with a thickness of 10 μm and a distribution of signal amplitude levels of the AE during the deformation in the stress area before and after the yield point

From Fig. 11 shows that the AE activity has a small absolute value. The dependence of AE activity during deformation of the sample coated stainless steel similar AE activity curve of the original sample without coating. However, it should be noted that the deposition process this coating results in hardening of the material, increasing its yield strength and slight decrease in elongation (compared with the initial state).

Multilayer coatings. For efficiency applied to different coating materials in recent years increasingly used technology of deposition of multi-layer and multi-component coatings. The principle of creating multi-layer coatings is that each layer needs to perform its function. For example, the first layer protects the product from the hydrogenation and increases its resistance to corrosion, second it improves the mechanical characteristics, a third is optional technological functions: aligning the thermal coefficient of linear expansion of the substrate material and coating, as well as adjacent layers, the reduction of internal stresses in the coating, improving adhesion, etc., or protects the inner layers. The effectiveness of each coating layer is determined simply by selecting a variety of the applied materials, their quantity and the sprayed layer thickness.

Let us consider the experimental data of testing of samples of zirconium alloy with the two-component bilayer and three-layer coatings Cr/CrN, CrAl/CrN, ZrCr/Cr/CrN. In Fig. 12 shows the dependence of strain and AE activity for the samples with two-layer two-component coating Cr/CrN with a thickness of 14 μm and amplitude distribution of AE signals.

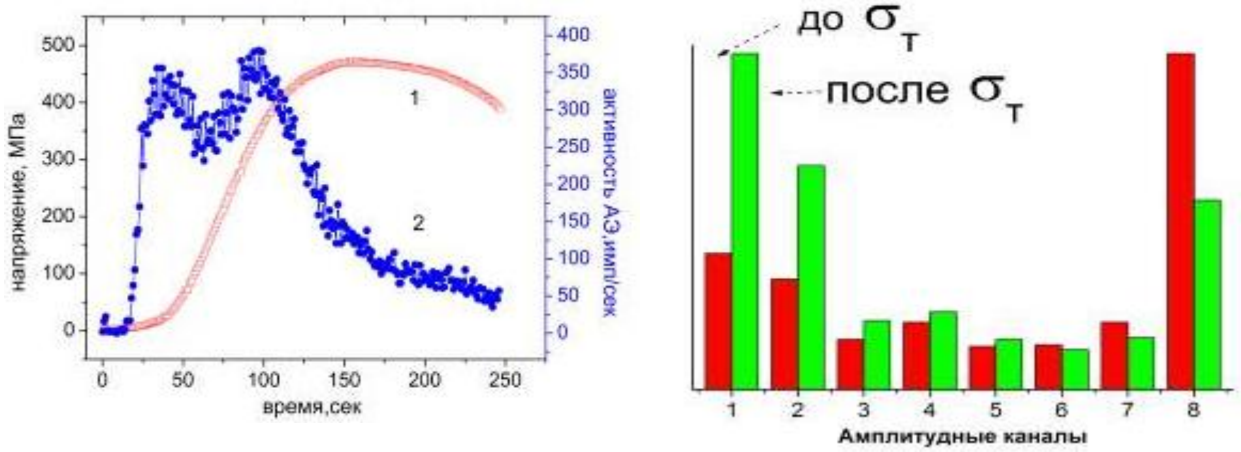

Fig. 12. The dependence of the stress (1) and AE activity (2) for the samples coated with two-layer bicomponent Cr/CrN thickness of 14 μm icrometers (outside) from the time of loading and distribution of the AE signals from the amplitude levels during deformation in area of stress before and after the yield point

From Fig. 12 shows that AE begins to register at the initial stage of deformation and increases dramatically already at stresses equal to one tenth of yield stress. AE activity curve for this coating has two peaks. The second peak of AE activity curve is in the region of the yield stress. During deformation of the samples in the stress range before and after yield stress is observed substantial differences in amplitude distribution of AE signals. If at the initial stage the spectrum is dominated by signals of high amplitude, when stresses above the yield limit begin to work intensively low-amplitude sources. Coating Cr/CrN thickness of 14 μm leads to hardening of the material and substantial decrease in elongation. Annealing at a temperature of 550^{o}C for 1 hour in vacuum does not change the type of dependency and activity of AE and amplitude distribution of AE signals (see Fig. 13). There is a slight increase in the elongation of the sample (see tab. 1).

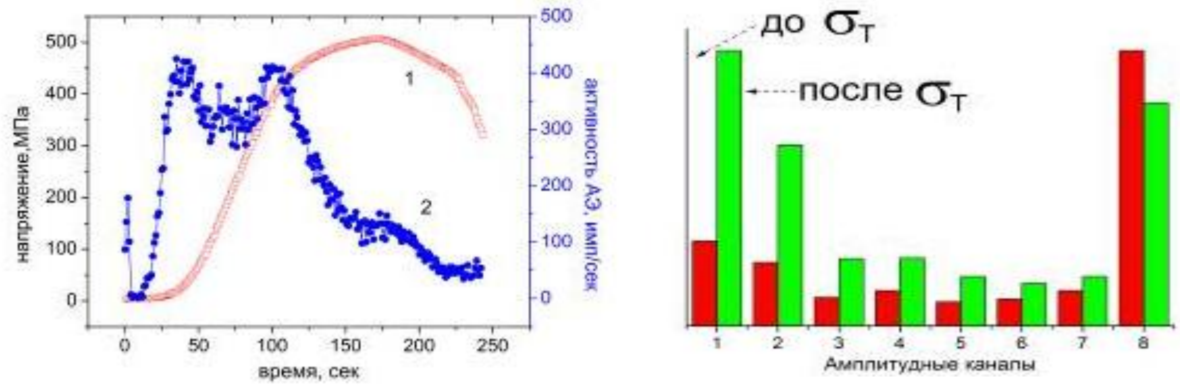

Fig. 13. The dependence of the stress (1) and activity AE (2) from the loading time and the AE signal distribution amplitude at deformation levels in the area stress before and after the yield point for the samples coated with the two-layer bicomponent Cr/CrN thickness of 14 μm (outside) after annealing in vacuum at 550 °C for 1 hour

It is known that addition of Al in the coating increases their hardness, wear resistance and heat resistance while maintaining the protective properties of the coating, is due to the formation on the surface is very durable and dense Al_2O_3 layer. In Fig. 14 shows the dependence of strain and AE activity from the time of loading for samples with double-layer coating CrAl/CrN with a thickness of 8.5 μm (from the outside) and amplitude distribution of AE signals.

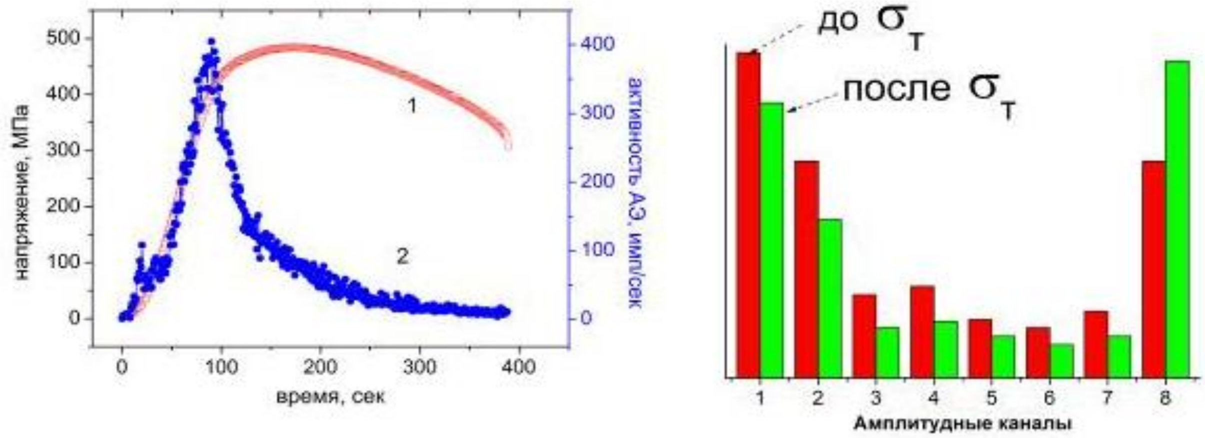

Fig. 14. The dependence of the stress (1) and AE activity (2) for the samples coated with two-layer bicomponent CrAl/CrN 8.5 μm thick (on the outside) and the distribution of the AE signal amplitude levels in the case of deformation stress before and after the yield point

From Fig. 14 shows that AE begins to register at the initial stage of deformation and increases in proportion with increase in applied stress. The peak of the curve of AE is the area of stresses equal to yield strength. During deformation of samples in the field of stress before and after the yield point there is a difference in the amplitude distribution of AE signals. The increase in high amplitude signals in the field of plastic flow, probably associated with the processes of initiation and propagation of cracks. The application of this coating leads to increase the tensile strength and the yield strength of the material, but reduces the elongation of the sample. Coatings, which have Cr and Al (see Table) significantly strengthen the material and still provide a high elongation values of the samples.

Fig. 15 shows the dependence of stress and AE activity for samples with a three-layer coating ZrCr/Cr/CrN thickness of 9 mm (from the outside).

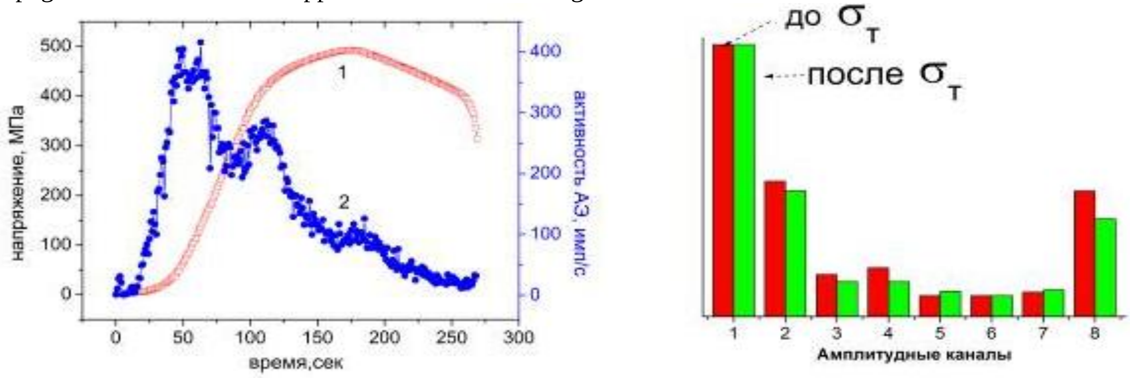

Fig. 15. The dependence of the stress (1) and AE activity (2) samples of coated ZrCr/Cr/CrN thickness of 9 μm (the outside) and the distribution of the AE signal amplitude levels during deformation in stress before and after the yield point

The appearance of the dependence of AE activity of the specimen with a three-layer coating ZrCr/Cr/CrN similar dependence of AE for the two-component coating ZrN thickness of 3 μm (although the absolute activity values above the latter about two times). From Fig. 15 shows that AE begins to register at the initial stage of deformation and increases with increasing applied stress reaching a first maximum at voltages equal to half the yield stress. The second peak on the curve activity of AE is in the region of the yield stress. Amplitude distribution of AE signals is almost the same with all the stresses of deformation. This coating significantly strengthens the material and reduces elongation of the sample.

CONCLUSIONS

1. Determined mechanical properties and acoustic parameters in tension of ring specimens of alloy Zr1%Nb, made from tubes of fuel after application of different coatings.

2. It is shown that the coating have a significant influence on strength and plastic characteristics of the sample. Comparative analysis of mechanical characteristics has allowed to establish that the ultimate strength increased by 15.5…16.5%, while the yield on 8…12,5% for samples with coatings 18Cr10NiTi, Cr/CrN, TiN. The preservation of plasticity (or slight increase) was detected for coatings CrAl; CrAl/CrN and ZrN (thickness 3 μm).

3. The best combination of mechanical properties has samples with coatings CrAl; CrAl/CrN and 18Cr10NiTi.

4. Analysis of the distribution of the amplitude spectrum of AE signals (especially high-amplitude component) recorded during the test specimens leads to the conclusion about the functional status of protective

coatings in the field of elastic and plastic deformation. The appearance of a large number of high-amplitude signals in the elastic deformation of the samples can mean intensive cracking of the coating. To confirm this assumption and analyze the mechanisms of deformation of the coated sample is necessary to conduct studies of microstructural

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Article received 02.09.2015

МЕХАНИЧЕСКИЕ СВОЙСТВА И АКУСТИЧЕСКИЕ ПАРАМЕТРЫ ТВЭЛЬНЫХ ТРУБ ИЗ СПЛАВА ЦИРКОНИЯ Zr1%Nb С ЗАЩИТНЫМИ ПОКРЫТИЯМИ

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Приведены результаты исследования влияния различных покрытий, нанесенных ионно-плазменным методом, на механические свойства и акустические параметры образцов твэльных трубок из сплава Zr1%Nb. Кольцевые образцы испытывали при комнатной температуре на растяжение в радиальном направлении. Показано, что покрытия существенно влияют на прочностные и пластические характеристики образцов. Так, предел прочности образцов с покрытиями Х18Н10Т, Cr/CrN, TiN увеличивается на 15…16,5%, а предел текучести – на 8…12,5%. Сохранение пластичности (или ее небольшой рост) обнаружено для покрытий CrAl, CrAl/CrN и ZrN. Наилучшим сочетанием механических свойств обладают образцы с покрытиями CrAl, CrAl/CrN и Х18Н10Т. Заключение о функциональном состоянии нанесенного защитного покрытия в областях упругой и пластической деформаций сделано с помощью амплитудного анализа сигналов акустической эмиссии, зарегистрированных в процессе механических испытаний.

МЕХАНІЧНІ ВЛАСТИВОСТІ ТА АКУСТИЧНІ ПАРАМЕТРИ ТВЕЛЬНИХ ТРУБ ЗІ СПЛАВУ ЦИРКОНІЮ Zr1%Nb ІЗ ЗАХИСНИМИ ПОКРИТТЯМИ

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Наведено результати дослідження впливу різних покриттів, нанесених іонно-плазмовим методом, на механічні властивості і акустичні параметри зразків твельних трубок зі сплаву Zr1% Nb. Кільцеві зразки випробували при кімнатній температурі на розтяг у радіальному напрямку. Показано, що покриття суттєво впливають на міцності і пластичні характеристики зразків. Так, межа міцності зразків з покриттями Х18Н10Т, Cr/CrN, TiN збільшується на 15,5…16,5%, а межа плинності на 8…12,5%. Збереження пластичності (або її невелике зростання) виявлено для покриттів CrAl, CrAl/CrN і ZrN. Найкраще поєднання механічних властивостей мають зразки з покриттями CrAl, CrAl/CrN і Х18Н10Т. Висновок про функціональний стан нанесеного захисного покриття в областях пружної і пластичної деформацій зроблено за допомогою амплітудного аналізу сигналів АЕ, які були зареєстровані в процесі випробування зразків.