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THE EFFECTIVENESS OF ION IMPACT TECHNOLOGY FOR ENHANCING THE STRUCTURAL STRENGTH OF PRODUCTS

Based on theoretical and experimental studies in the fields of solid-state physics and physical materials science, it is proved that the deformable surface layer of a solid body is an independent functional subsystem and radically influences the scale levels of plastic flow and product destruction altogether [1].

It is known that the behaviour of the outer and inner layers of metal under tension differs even without any special surface treatment, primarily due to the uncompensated nature of surface atomic bonds. The difference in the rates of self-organisation of structures in the surface layers and the internal volumes of the metal persists throughout the entire deformation process right up to the onset of failure [2–4].

The surface plays a significant role in the deformation behaviour of a solid and determines the nature, location and timing of failure. State of the surface layer and its interface with the bulk substrate determines significant differences in the behavior of the surface and internal layers of metal under deformation [1,5], makes changes in the tensile diagram and nature of product destruction [6,7].

The condition of the surface layer can be altered by various modification methods: by surface hardening, chemical-thermal treatment, plastic deformation, high-intensity ultrasonic shock treatment, the application of various coatings, including the very common ion-plasma treatment (IPT), which consists of two stages – ion bombardment and coating deposition. In modern industry, IPT is widely used to alter the properties of surface layers when applying various coatings (to achieve ultra-high hardness and improve the durability of cutting tools, reduce the coefficient of friction between contacting parts and increase their wear resistance, enhance the corrosion resistance of products, etc.). In this case, the ion bombardment (IB) stage is considered only as an auxiliary process and is intended to clean the surface of contaminants and improve adhesion between the metal of the part and the

coating. At the same time, IB affects changes in the surface structure, surface roughness and stress state, and all these factors can be decisive in determining the behaviour of a specimen (product) under load. Therefore, in our view, IB can be regarded as a standalone treatment that can radically alter the properties of a product.

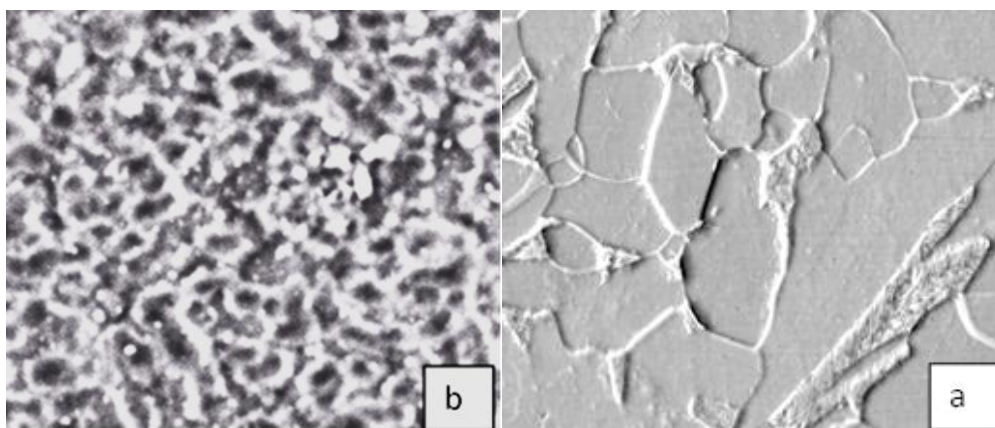
The following objectives were addressed in this study:

- to investigate the process of surface layer formation during ion bombardment with low-energy ions;

- to examine the influence of the origin and thickness of the modified surface layer on the behaviour and changes in the properties of steel samples under tensile loading.

The experiments were carried out on standard cylindrical samples ($l_0 = 25$ mm, $d = 5$ mm) of annealed steel 20, which were subjected to ion bombardment (IB) by low-energy (up to 3 keV) titanium ions at the "Bulat-3t" installation in the argon atmosphere. For the sake of uniform processing, the samples were being turned around the axis.

Microstructural analysis recorded significant grinding of ferrite grains: before IB, the average grain size was equal to 40 μm and in the middle of their sub-boundaries were not detected (Fig. 1). After IB, a developed substructure with an element size of 150 - 200 nm and with clear sub-boundaries with a width of 130 - 255 nm. As is known, such a fine structure model is characteristic of nanomaterials. It was also revealed that during the bombardment of the surface, individual small drops of titanium, settling on the dents, cracks, etc., "heal" these surface defects (Fig. 2), which are concentrators of stresses. It is definitely a positive factor.



a – annealing; b – annealing + IB

Fig. 1. Microstructure of steel 20; $\times 8000$

The investigated surface roughness of the samples before and after IB indicates that the roughness index Ra after IB decreases from 1.26 to 0.20 μm . The decrease

in this characteristic is a consequence of the smoothness of the surface relief during ion-plasma treatment.

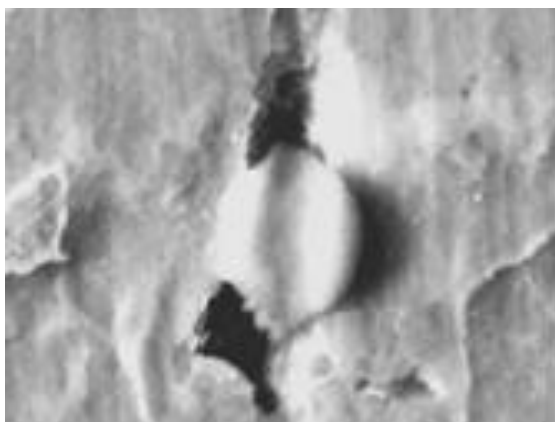


Fig. 2. A drop of Ti in the dent on the non-treated surface of the sample, $\times 10000$

To determine the nanohardness of a thin modified layer the method of calculating the average contact pressure for each point of the indentation load diagram (Fig. 3), developed by S.N. Dub [8]. On the surface, a nanoparticle of 11 GPa is registered, at a depth of 30 nm it sharply decreases to 5 GPa, and then decreases monotonically, and approaches the initial 2.7 GPa at a depth of 100 nm. Under the influence of IB, a thin layer (up to 1 μm) formed on the surface, characterised by ultrafine grains, a well-developed substructure, a nanohardness increased by almost four times, and a significantly smoothed surface. It should be noted that the structure of the sample core remains unchanged.

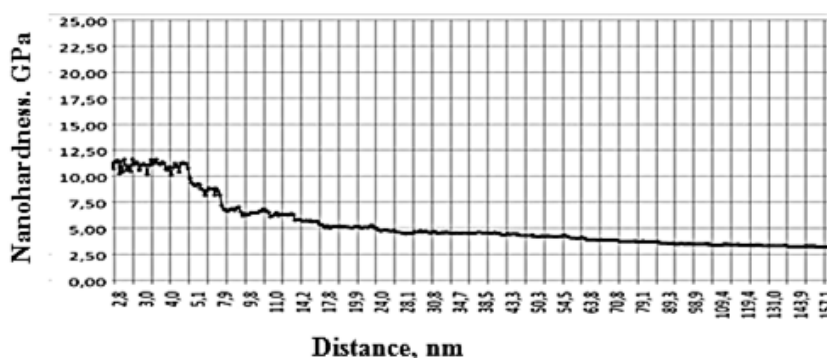
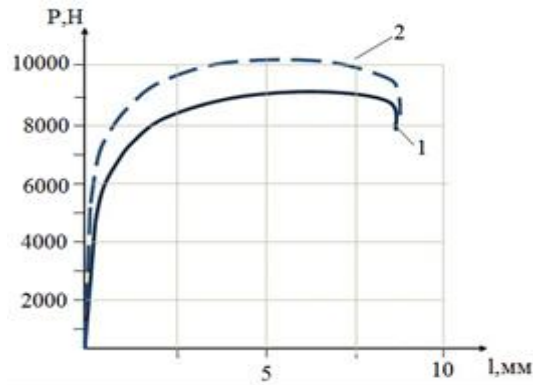


Fig. 3. Nanohardness curves following calculation using the SKD method [8]

In order to investigate the effect of the state of the thin ($<1 \mu\text{m}$) modified surface layer on the deformation behavior of the samples and the nature of fracture,

the tensile tests were performed.

Figure 4 shows the curves $P = f(\Delta l)$ for standard cylindrical steel 20 samples with different surface layer condition.



1 – annealing; 2 – annealing + IB

Fig. 4. Curves of steel 20 strain

After IB, the curve 2 of strain in the elastic area is steeper than for the annealed state - curve 1, which indicates an increase in the modulus of elasticity. These data show that IB increases strength without reducing ductility. After removing the modified layer, the properties return to their original state (without IB). Thus, direct experiments proved that the point is not a change in the material properties, but a different behavior of the sample after IB.

The quantitative values of the mechanical properties are shown in Table 1. The results obtained indicate that the IB surface significantly increases the strength (σ_B by 16% and $\sigma_{0.2}$ by 26%), while reducing the likelihood of brittle fracture, as high S_k and characteristics of ductility remain. The microhardness remains unchanged, i.e., at the depth of penetration of the indenter (Vickers diamond pyramid), the hardening is not recorded.

Table 1

Mechanic characteristics of steel 20 samples after different treatment

State	σ_B , MPa	$\sigma_{0.2}$, MPa	S_k , MPa	δ , %	ψ , %	HV 5/15
Annealing	445	230	910	31	58	130-133
Annealing + IB	515	290	1010	35	62	129-133
Removed layer	440	230	908	30	60	128-132

It should be noted that no method of volumetric treatment (hydro-extrusion, thermomechanical treatment, intensive plastic deformation) can achieve a

significant increase in strength while maintaining (not to mention increasing) high ductility.

Low-energy ion bombardment of surfaces should be regarded as an effective treatment method in its own right, which enhances the structural strength and operational reliability of products, a fact that is undoubtedly of practical interest.

References:

1. Panin V.E., Grinyaev Yu.V. , Panin A.V., Panin S.V, Multilevel wave model of a deformed solid in physical mesomechanics, *Multiscaling in Applied Science and Emerging Technology. Fundamentals and Applications in Mesomechanics*. Proceedings of the Sixth International Conference for Mesomechanics. – 2004. P. 335 – 342.
2. Vilyis J., Čiuplys V., Terentjev V., Kolmakov A. et al., Particularities of Plastic Deformation of Metals Near Surface Layers., Kaunas: Technologija, 2003, 208 p
3. Wang Z., Lu K. Diffusion and surface alloying of gradient nanostructured metals // *Beilstein Journal of Nanotechnology*. – 2017. – Vol. 8. – P. 547–560
4. Zhang Y., Lu K. Surface nanocrystallization of metallic materials // *Progress in Materials Science*. – 2022. – Vol. 123. – 100789.
5. Doshchechkina I.V., D'yachenko S.S, Ponomarenko I.V., Tatarkina I.S. Improving the plasticity of thin cold-rolled steel sheet for cold stamping. *Steel in Translation*. 2021. Vol. 46. P. 364 – 367.
6. D'yachenko S.S., Doshchechkina, I.V., Ponomarenko I.V., Tatarkina I.S. Use of the Ion-Plasma Treatment for Improving the Structural Strength of Items *Jornal of Nano - and Electronic Physics*. Vol. 4, Sumy State University. 2012. P.1–4.
7. D'yachenko S.S. Doshchechkina, I.V., Ponomarenko I.V., Tatarkina I.S. Using ion plasma treatment to increase the structural strength of products. *National Bulletin Lviv Polytechnic University* . Lviv Polytechnic. 2011. No. 713. P. 166 –171.
8. Dub S. N., Novikov N. V. Testing solids for nanohardness. *Superhard Materials* – 2004. – No. 6. – P. 16–33.