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The Influence of ultrasonic strengthening treatment on microhardness of the construction materials surface with different initial structure

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Abstract. The description of the method of ultrasonic surface hardening treatment (UST), which makes it possible to form gradient structures in structural materials, is given. This paper presents the results of the effect of UST on the surface microhardness of coarse-grained, ultrafine-grained and nanostructured titanium nickelide. The work is devoted to the study of the effect of ultrasonic hardening surface treatment on the surface microhardness of structural materials with different initial structures (coarse-grained, ultrafine-grained, nanostructured).

1. Introduction

Methods for obtaining nanostructures in structural materials can be divided into two main classes: volumetric and surface nanostructuring. These methods are well known. Among the methods of bulk nanostructuring, we should especially note the methods of severe plastic deformation (SPD), since it is these methods that make it possible to obtain non-porous bulk structural materials with ultrafine grain sizes [1–6].

The main SPD schemes include severe plastic deformation by torsion and the method of equal channel angular pressing. Methods based on multiple rolling can also be referred to the methods of severe plastic deformation. With these loading patterns, shear deformations predominate, and an increase in the number of machining cycles allows extremely high deformation rates to be obtained.

Thus, the main technological equipment for grinding and activating constructional materials (clay, gypsum, soft coal, lumpy lime, etc.) are ball drum and high-speed hammer mills [7, 8]. At the same time, the working process is carried out in them by grinding bodies on the principle of crushing and abrasion, which requires sufficiently high energy consumption with a significant material consumption of this equipment (energy costs for grinding reach 30-40 kW h/t).

The most promising methods of surface nanostructuring include surface ultrasonic hardening treatment (UST) [7–8]. The scientific basis of this method is the theory of plastic deformation in

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conjunction with the results of studies of the processes associated with the use of ultrasound. The RCD uses the energy of mechanical vibrations of the indenter. The vibration amplitude is in the range from 0.5 to 50 microns. Oscillations are performed at ultrasonic frequency. Energy is introduced into the processing zone by the static force of pressing the indenter to the surface of the workpiece. The composition of technological equipment for ultrasonic surface treatment is shown in Figure 1.

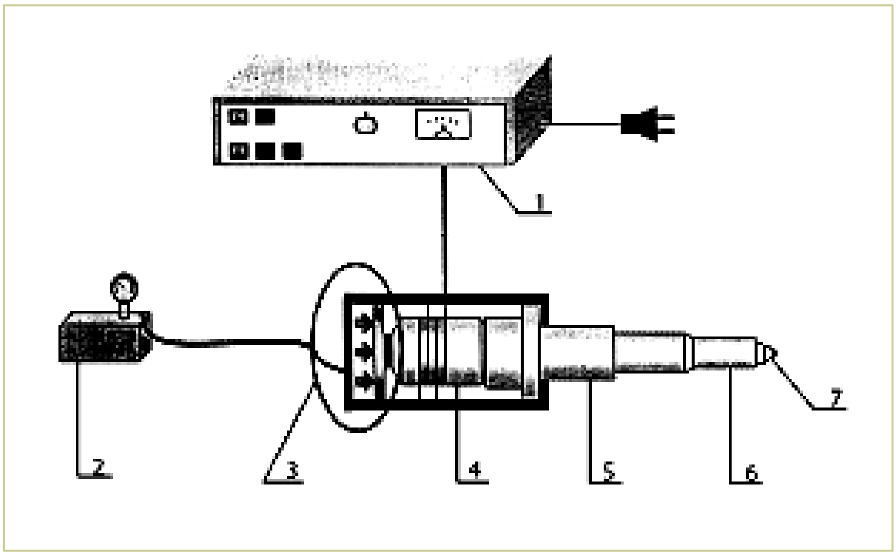

Figure 1 - Technological equipment for ultrasonic treatment: 1 - ultrasonic generator; 2 - air compressor to provide static load on the indenter; 3 - mechanism for adjusting the force provided by the pneumatic system; 4 - piezo or magnetostrictive transducer; 5 - booster; 6 - waveguide; 7 - indenter

Ultrasonic surface treatment effectively hardens and significantly improves the surface quality of the workpiece. In particular, a significant increase in the microhardness of the surface layer is noted.

In recent years, issues related to the production of gradient structures in structural materials, including nanostructures, have been actively studied, which makes it possible to obtain products with a different structure on its surface and in volume. It is the RCD that is one of the ways to form a gradient structure. For example, the possibility of forming a gradient structure with a surface nanostructure in bulk products made of structural materials using surface ultrasonic hardening treatment and a gradient nanostructure using a combination of electroplastic rolling and ultrasonic treatment is shown [9, 10].

2. Materials and Methods

Titanium nickelide Ti49.3Ni50.7 was chosen as the object of research. This alloy has a number of unique properties, such as, for example, the effects of thermomechanical memory, mechanocyclic, mechanothermal and thermocyclic durability, weldability, corrosion resistance, comparative simplicity of chemical composition and manufacturability. Titanium nickelide is one of the most promising materials in mechanical engineering. For example, it can be used to create tight and permanent joints in conditions where the use of traditional technologies is impossible. Titanium nickelide can be used to manufacture passive safety elements for nuclear power. First of all, these are flow shutters - direct acting shape memory devices.

To obtain an ultrafine-grained state, the investigated coarse-grained shape memory alloy Ti49.3Ni50.7 in the quenched state, having a microstructure in the form of polyhedral grains with an average size of 80 μm, was subjected to equal channel angular pressing and subsequent thermomechanical treatment [9–10]. As a result, a grain-subgrain microstructure with an average element size of about 1 μm was formed in the alloy.

Nanostructured samples of titanium nickelide were obtained from a coarse-grained alloy by multiple rolling using a pulsed current [11–12]. Rolling was performed on a two-roll mill equipped with a pulse current generator. After each rolling step, the samples were cooled in water. Multiple electroplastic rolling and subsequent annealing resulted in the production of samples with a homogeneous nanostructure with a grain size of 40–50 nm.
Then the samples in the coarse-grained (CG), ultrafine-grained (UFG) and nanostructured (NS) states were subjected to UST. The processing of experimental samples was carried out on a milling machine, on the support of which an ultrasonic tool was fixed. In the process of RCD, only the static load (the force pressing the indenter to the processed sample) changed - 50 N, 100 N, and the vibration amplitude of the indenter (20 μm), the linear processing speed (0.37 m / min), the feed rate of the processed sample (0, 15 mm), the diameter of the indenter of the ultrasonic instrument (10 mm) and the temperature of the water cooling of the sample (t = 10oC) were constant. Figure 2 shows the appearance of an ultrafine-grained titanium nickelide sample after ultrasonic surface treatment. The area treated with the RCD has a mirror finish.

Figure 2. Appearance of a sample of ultrafine-grained titanium nickelide after ultrasonic hardening treatment

In the experiment, the static pressure was varied, since this is one of the main technological parameters of ultrasonic hardening. It determines the microgeometry of the treated surface, the degree and depth of work hardening, the magnitude of the stresses arising in the surface layer, the physical and mechanical properties of the surface. This influence is due to the very nature of the formation of the surface layer during plastic deformation by an ultrasonic instrument. In addition, the static pressure is quite easy to change during the RCD process. A small value of static pressure does not provide sufficient deformation of the surface layer, and its excessive increase leads to over-riveting. This raises the question of determining the optimal value of the static pressure.
The microhardness of the samples was measured and calculated according to GOST 2999-75. The measurement was carried out by the Vickers method. To determine the microhardness of the surface of the samples, a PMT-3 microhardness tester was used. Good repeatability and stability of measurement results were obtained at a load of 50 g. At the same time, at least ten prints were obtained for each test sample.

3. Results and Discussions

The results of experimental studies have shown that ultrasonic hardening surface treatment significantly affects the microhardness of the treated surface (Figure 3).

The analysis of the obtained experimental data showed (see Fig. 3) that for coarse-grained titanium nickelide the surface microhardness after UST with a static pressure of 50 N increases sharply. Its growth is about 48%. When the static load changes from 50 to 100 N, the microhardness also increases, but this increase is 1.5-1.7% less than in the case of a load of 50 N. For ultrafine-grained titanium nickelide, the surface microhardness increases uniformly with an increase in static pressure from 50 to 100 H on average by 12%. The best result in terms of surface microhardness was obtained by processing ultrafine-grained titanium nickelide with a static pressure of 100 N.

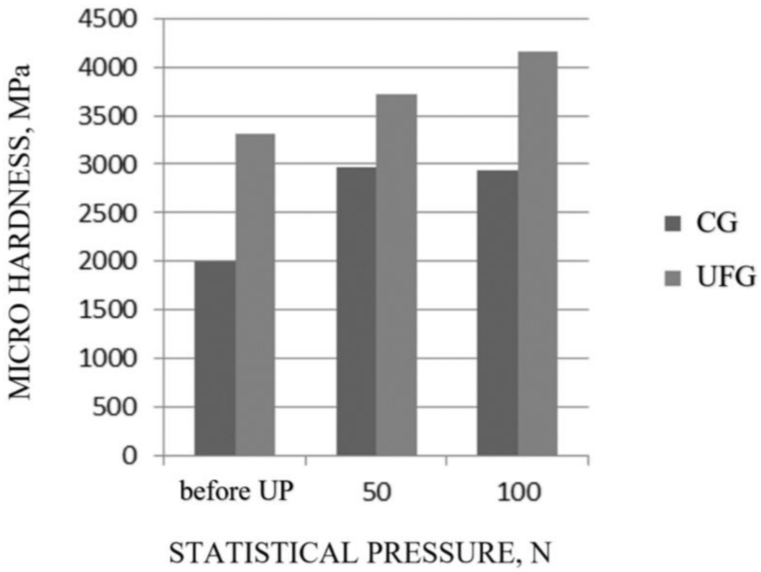

Figure 3. Dependence of the surface microhardness of coarse-grained and ultra-fine-grained titanium nickelide against static pressure during RCD

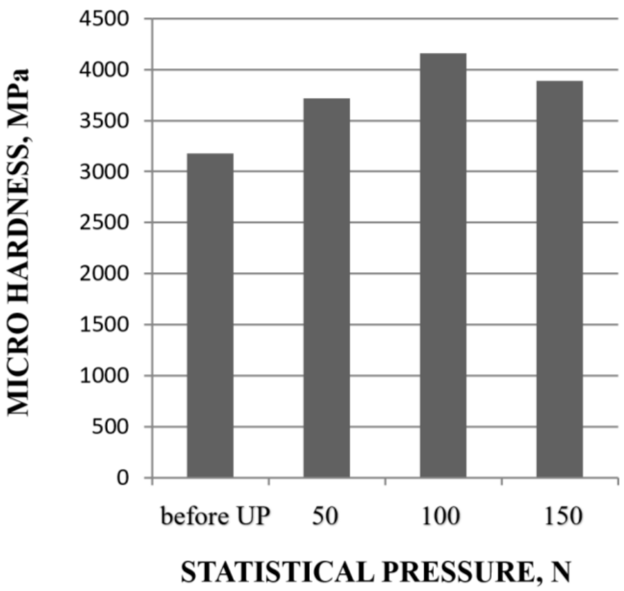

Figure 4. Micro hardness of nanostructured titanium nickelide depending on static pressure during ultrasonic treatment

Because of the surface deformation of nanostructured titanium nickelide by the UST method, an increase in the surface microhardness is also noted [11, 12]. We studied samples of titanium nickelide Ti49.3Ni50.7 after electroplastic rolling and subsequent annealing, having a homogeneous

nanostructure with a grain size of 40–50 nm. Subsequent ultrasonic treatment reduces the grain size on the surface to 20–30 nm. The largest increase in microhardness of the order of 31% is given by the UST of the surface with a static pressure of 100 N (Figure 4). The microhardness of the surface layer as a result of the combined processing of coarse-grained titanium nickelide by the method of multiple electroplastic rolling and UST reaches 4200 MPa.
Figure 5 shows the dependence of the growth of microhardness on the type of processing of titanium nickelide and, accordingly, its structure. Electroplastic rolling makes it possible to form a nanostructure in the bulk of the sample under study.

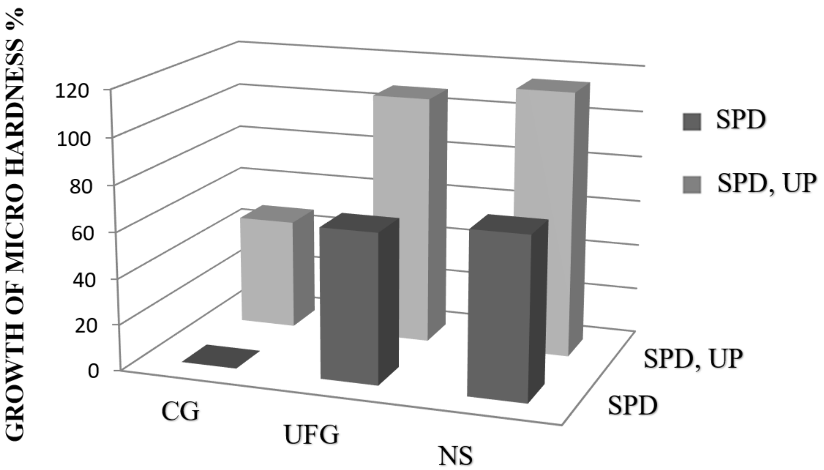

Figure 5. The growth of titanium nickelide microhardness depending on the type of processing

The increase in the microhardness of the surface of a nanostructured sample obtained as a result of repeated electroplastic rolling, compared with the initial coarse-grained state, is about 70%, and after combined processing (multiple rolling with current and UST) - more than 115%. The method of equal-channel angular pressing leads to an increase in the surface microhardness in comparison with the initial coarse-grained state of titanium nickelide by 65%, and UST increases this figure to 108%.
Thus, the results of the studies performed show that ultrasonic surface hardening treatment leads to an increase in the microhardness of the titanium nickelide surface both in the coarse-grained, in the ultrafine-grained, and in the nanostructural states. The maximum value of the surface microhardness after UST obtained for ultrafine-grained and nanostructured titanium nickelide is 4160 MPa and 4200 MPa, respectively, and for coarse-grained titanium nickelide - 2970 MPa.
The authors note that the results described in this study should become the foundation for further work in the field of creating and optimizing the technology of ultrasonic surface hardening treatment in order to obtain gradient structures (nanostructures) in structural materials.

4. Conclusions

1. Ultrasonic surface treatment of the Ti49.3Ni50.7 shape memory alloy increases the microhardness of its surface by about 50%, if the initial state is coarse-grained, by about 30%, if the initial state is ultrafine-grained or nanostructured.2. The most effective of the existing types and technical solutions for the preparation of activated (concentrated) cements is an aerodinamic impact activator with an increased number of working zones and a rational location of the working body.
2. A significant increase in the microhardness of titanium nickelide after UST, repeated rolling with current, equal-channel angular pressing, as well as their combinations, is associated with an increase in the dispersion of the structure. The microhardness of the surface of ultrafine-grained and nanostructured titanium nickelide after UST differs insignificantly, and we can talk about the achievement of some deformation saturation of the alloy. This is explained by the fact that an increase

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in the dispersion of the structure leads to an increase in the specific boundaries of blocks, where deformation is difficult.

3. Static pressure (the force pressing the indenter to the product) with an RCD is a significant technological parameter. For the treatment of coarse-grained titanium nickelide, a static pressure of 50 N is recommended. The recommended static pressure for ultrasonic surface hardening of ultrafine-grained and nanostructured titanium nickelide is a pressure of 100 N.

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