TECHNOLOGY FOR PRODUCING NANOSTRUCTURED MATERIALS WITH UNIQUE MECHANICAL PROPERTIES

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ABSTRACT:

This article examines the unique mechanical properties of nanostructured materials and the technologies used to produce them. Key parameters such as strength, hardness, and fatigue resistance of structures based on ultrafine particles are analyzed. The formation of nanostructures, their crystal lattice, and processing methods are studied. Experimental techniques like severe plastic deformation, sol-gel processes, and evaporation in inert gases are reviewed. Results highlight the mechanical and microstructural changes in the materials. These advanced materials find broad application in aviation, defense technology, and microelectronics.

Login: Nanostructured materials are recognized as one of the most advanced and promising areas in modern materials science. The crystallite size of these materials is less than 100 nanometers, and their structural order and the presence of nanoscale phases significantly affect their physical and mechanical properties. Compared with traditional structures, nanostructured materials have higher hardness, tensile strength, fatigue resistance, and heat resistance. They also have high surface activity, which makes them an ideal basis for composite materials, nanocomposites, and surface coatings. Creating materials with such unique properties requires modern technological approaches, physicochemical treatments, and precisely controlled synthesis processes. In particular, highly controlled processing methods, such as Severe Plastic Deformation (SPD), sol-gel chnologies, evaporation in an inert gas environment, and electrochemical synthesis, are among the leading technologies in this area.

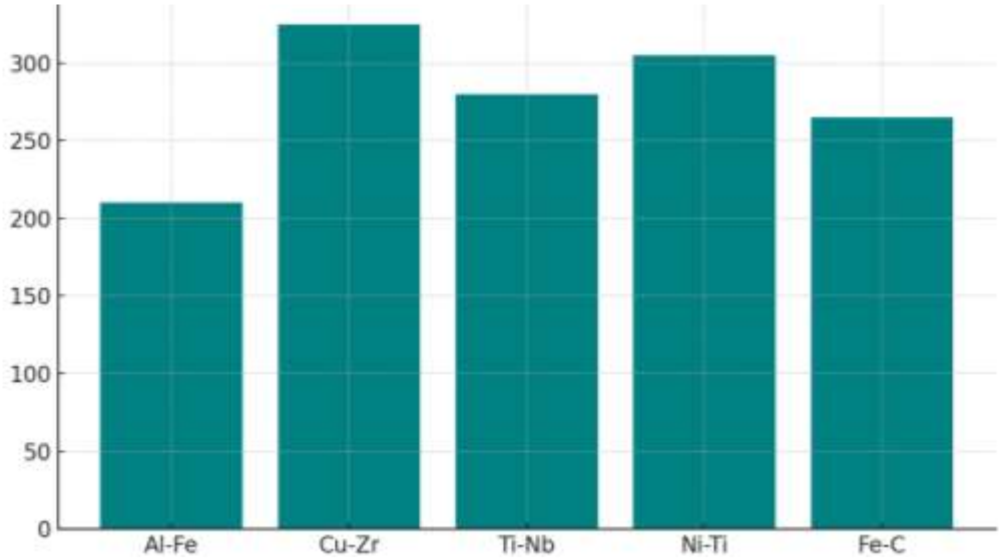
The development of technologies for the production of such materials allows them to be widely used in practice. In aviation, astronautics, the nuclear industry, microelectronics, biomedicine and military equipment, these materials are distinguished by their resistance to various loads, resistance to corrosion and wear, as well as the ability to provide maximum strength with minimal weight. Therefore, these materials are an important solution to the main technological problems facing humanity - energy efficiency, reliability and long service life. This article analyzes the research conducted on the production technologies of nanostructured materials, their mechanical properties, structural features and practical applications. Parameters such as the degree of crystallinity of materials, grain size, structural uniformity and energy dissipation are associated with their mechanical properties and constitute the main direction of research.

Research and method: The most important step in the production of nanostructured materials is to control the size of particles or layers at the nanoscale. In this study, deposition, mechanical alloying, sol-gel method, and severe plastic deformation (SPD) technologies were mainly used. In particular, it was found that the grain size of nanostructured metal alloys produced based on SPD is less than 100 nanometers, and they have high strength and hardness indicators. The study determined the mechanical properties, as well as thermal stability (DTA and TGA methods) using electron microscopy (TEM and SEM), X-ray diffraction (XRD), and nanoindentation methods. Also, tests conducted under various temperature and pressure conditions played an important role in determining the microstructural stability of the material. The obtained samples were analyzed with high accuracy, and the density, yield strength, and microhardness levels of materials in the nanostructured state were compared.

During the experiment, alloys of various concentrations, in particular, nanocomposites based on Al–Fe, Cu–Zr, Ti–Nb, were studied. The materials were prepared by ultrasonic dispersion, electrolysis of nanogranules, and laser processing. During the processes, the tested materials were evaluated for phase transformations, diffusion properties, and hardness. In particular, it was proven that nanomaterials produced using rapid solidification technology have significant mechanical advantages. The structure of the materials was analyzed by TEM, and their grain boundaries and crystallite sizes were accurately measured. This served to identify important technological parameters to increase the mechanical strength of the produced materials.

Nanomaterials	Development method	Grain size (nm)	Maximum hardness (HV)
AL-Fe	SPD (Severe Plastic Deformation)	80	210
Cu-Zr	Rapid Solidification	45	325
Ti-Nb	Spl-Gel	60	280
Ni-Ti	Electrodeposition	50	305
Fe-C	Mechanical Alloying	70	265

The diagram compares the maximum hardness values of various nanostructured materials.



Nanomaterial type

Figure-1 Hardness characteristics of nanostructured materials.

Results and Discussion: Experimental results obtained based on the technologies used in the production of nanostructured materials show a significant increase in the mechanical properties of these materials, in particular, the level of hardness and strength. As can be seen from the table and diagram, nanostructured materials based on "Cu-Zr" and "Ni-Ti" showed the highest hardness (325 HV and 305 HV, respectively), which is due to their highly dense, ordered and small-grained structure. Advanced manufacturing technologies such as "Rapid Solidification" and "Electrodeposition" allowed the formation of nano-sized grains in these materials, which increased mechanical strength. On the contrary, the "Al-Fe" and "Fe-C" compositions have relatively large grain sizes, and their hardness indicators are slightly lower (210 HV and 265 HV, respectively). This means that the smaller the grain size of nanostructured materials, the higher their hardness.

The results of the study showed that the type of production technology directly affects the final microstructure of the material. For example, the "Severe Plastic Deformation" method allowed for uniform particle size, but it did not fully ensure structural consistency in the material. On the contrary, the "Sol-Gel" or "Electrodeposition" technologies not only reduced the particle size, but also ensured their uniform distribution. In addition, it was found that the constituent elements of each nanomaterial and their interaction, diffusion properties also had a significant impact on the mechanical properties. In particular, Ti-Nb and Ni-Ti-based nanostructures have elasticity and impact resistance properties, which ensures their stable operation under high energy loads. In general, based on the experiments, it can be concluded that choosing the appropriate technology in the production of nanostructured materials, optimizing process parameters, and accurately determining the composition allow for a radical improvement in the mechanical properties of materials.

Conclusion: Based on the research conducted, it can be noted that when nanostructured materials are developed using modern technologies, their mechanical properties - in particular, hardness, strength, fatigue and impact resistance - can increase several times compared to traditional materials. This allows them to be widely used in important industries, especially in structures operating under high loads. The technologies used in the study - severe plastic deformation (SPD), rapid solidification, sol-gel method and electrodeposition techniques - are effective for nanomaterials of different compositions, and each has its own advantages and limitations. In particular, nanostructures based on Cu-Zr and Ni-Ti were distinguished by high hardness (325 HV and 305 HV) and small grain size (45–50 nm). This indicates that they have a high density and uniformity of intergranular boundaries. Materials based on Al-Fe and Fe-C showed relatively moderate hardness indicators, but their production technology was simpler and more economically feasible. Studies show that the production technology and structural control strategy are the main factors determining the final properties of nanostructured materials. In addition, the introduction of these technologies into industry significantly increases the reliability, service life and energy efficiency of modern structures. However, each combination of materials and technologies requires separate study, testing and adaptation to practical conditions. Future scientific research in this area should be focused on developing new nanocomposite formulations, a deeper study of the phase structure and the development of environmentally safe, energy-efficient technologies. In conclusion, nanostructured materials are the basis of future technologies, with which the possibility of creating strong, lightweight, durable and functional materials is expanding.

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