Creation of new functional nanocomposites based on iron-nickel and copper alloys

Aims and field of the project: The purpose of the research project is to develop the novel functional nanostructured composite materials with shape memory effect (SME) and superelasticity (SE) for the creation of a new generation technology in aerospace and automotive sector, in instrumental and mechanical engineering, in electronics, biomedicine. By development of physical principles of a conceptually new resource-saving technology achieves the design of the shapes memory effect and superelasticity by changing the chemical composition, size and volume fraction of nanoparticles coherently bounded to a matrix in a nanocomposite.

Field of the project is Material science.

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2. Relevant publications

Ukraine
1. Titenko A., Demchenko L., Kozlova L., Babanli M. (2018) Effect of Thermomechanical Treatment on Mechanical Properties of Ferromagnetic Fe-Ni-Co-Ti Alloy.// In: Stebner A., Olson G. (eds) Proceedings of the International Conference on Martensitic Transformations: Chicago. The Minerals, Metals & Materials Series. Springer, Cham, 2018, P. 115-120, Book ISBN: 978-3-319-76967-7, https://doi.org/10.1007/978-3-319-76968-4_18

2. Titenko, A.N., Demchenko, L.D., Perekos, A.O., Gerasimov O. Yu. Effect of Thermomagnetic Treatment on Structure and Properties of Cu–Al–Mn Alloy Nanoscale Res Lett (2017) 12: 285. doi:10.1186/s11671-017-2052-6

3. A. Titenko and L. Demchenko. Effect of Annealing in Magnetic Field on Ferromagnetic Nanoparticle Formation in Cu-Al-Mn Alloy with Induced Martensite Transformation// Nanoscale Research Letters (2016) 11:237, DOI 10.1186/s11671-016-1453-2

4. А. Н. Титенко, Л. Д. Демченко, А. Е. Перекос, А. Ю. Герасимов Влияние отжига в магнитном поле на магнитные и механические свойства сплава Cu–Al–Mn // Наносистеми, наноматеріали, нанотехнології (Nanosistemi, Nanomateriali, Nanotehnologii), 2016, т. 14, № 2, с. 309–317

5. А. М. Тітенко, А. О. Перекос, Л. Д. Демченко Мартенситне перетворення при формуванні системи наночастинок у стопі Cu–Al–Mn після відпалу в магнітному полі // Наносистеми, наноматеріали, нанотехнології, 2014. - т. 12, № 1. - с. 123–132.

3. Background of the project

A priority and very promising direction in the field of material science are the development of intellectual materials with functional properties, which include the shape memory effect and superelasticity. The increased interest in materials targets to the elements of intellectuality (smart materials) and their reversible phase structure provides the possibilities of their flexible use as active elements (actuators) of micro-sensors and micro-drives, dampers for vibration damping of machines and mechanisms, in power executive mechanisms of various devices, and others. Widespread use of such materials in aerospace and automotive complex, in instrumentation and mechanical engineering, electronics, biomedicine, etc. allows them to occupy a priority place in the hierarchy of the most demanded materials.

The research aimed on creating shape memory nanocomposites based on alloys of iron and copper - as a new class of functional materials - are primarily due to their unique properties and a complex of physical and mechanical properties. The precipitation of nanosized particles of different chemical composition, size and volume fraction during aging is a promising approach to the creation of a new class of high-strength functional materials with SME and SE based on natural nanocomposites. Nanoparticles produced by dispersion hardening do not undergo martensitic transformation (MT), but due to variation in their chemical composition, size and volume fraction it is possible to control simultaneously the mechanical and functional properties of the material and, thus, to obtain nanocomposites with the necessary complex of service properties. The authors of the project in their work approach the creation of nanocomposite materials with SME based on iron and copper, which by their characteristics are close to the known world analogues. Thus, according to the mechanical properties, such new materials significantly outperform commercial Nitinol based alloys, so in Fe-based alloys, the level of superelastic deformation >13.5% (Nitinol ≤8%), the martensite induction stress >800MPa (Nitinol ≤600MPa), and as per the magnetic properties they exceed Heusler alloys (magnetization in Fe-based alloys are 3 times bigger and Curie temperature can be varied in the wide range).

The influence of thermomechanical and thermomagnetic treatment on functional and mechanical properties of Fe-Ni-Co-Ti, Fe-Ni-Co-Ti-Cu, Cu-Al-Mn and others was studied at Engineering and physical faculty of NTUU "KPI". The authors found that the precipitation of nanosized particles of the strengthening phase under dispersion hardening during the aging creates conditions for the formation of a high-strength state and the appearance of high-temperature SE. Our previous experimental studies showed that the ferromagnetic β_3-phase Cu_2AlMn nanoparticles formed in Cu-Al-Mn alloys when aged in a magnetic field: 1) provide a decrease in stress states that arise under martensitic transformations; 2) contribute to the growth of the effect of elasticity and thermoelasticity. The oriented growth of precipitated phase nanoparticles in the direction of applied magnetic field and the increase of their volume fraction contribute to reversibility of induced martensitic transformation as well. The authors of the project also found that an increase in elastic deformation, as well as thermoelasticity of iron-based alloys, in particular Fe-Ni-Co-Ti, can be achieved by precipitation of γ'-phase $(CoNi)_3Ti$ particles as a result of aging of high-temperature phase and providing magnetic ordering , which reduces the volume effect $\Delta V/V^{\gamma\leftrightarrow\alpha}{}_{\gamma}$ of martensitic transformation. An additional stimulus to increase these effects can be an additional strengthening of the yield strength of γ (austenitic) and α (martensitic) phases to retain the coherence of interphase boundaries at nucleation and growth of martensitic crystals as a result of combined thermomechanical treatment.

In the group of Professor Tiezhen Ren, various nanostructured materials have been widely investigated. The peculiarities of structure and properties of nanosized metal compounds have been studied in detail and the results have been published. The methods of X-ray crystallography and electronic crystallography for single crystals were used for the analysis of nanostructured metal compounds. The work is planned to focus on a more detailed study of nanostructured metallic materials and their properties from a theoretical and practical point of view. Therefore, in the group of Professor Tietzen Ren, the nanostructured metal materials for the creation of new functional nanocomposites will be manufactured and studied in detail.