Key-note report

Key Technical Advances for Optimizing Bulk Nanostructured Metals for Applications

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Nanomaterials have been at the forefront of nanoscale research and subsequent product commercialization since the expansion of nanotechnology in the 1990s. Excluding the semiconductor industry, in 2007 nearly 90% of nanotechnology products in the U.S. were nanomaterials. Nanoparticles, nanofibers, nanotubes, nanolayers, and other nanoscale structures have been incorporated into products in U.S markets with a total value that now exceeds $87 billion.

Bulk nanostructured metals and alloys are positioned to emerge as a significant portion of the nanomaterials sector, but only as we further understand three particular nanometal characteristics: the effects of nanoscale inhomogeneity on macroscale properties, the long term stability of nanostructures, and environmental interactions of nanostructured surfaces. This work examines each of these areas, summarizing the limitations of current research and recommending specific developments that are needed. As these areas are addressed it becomes easier to optimize one or more of the emerging continuous manufacturing technologies that will in turn allow widespread application of bulk nanostructured metals.

Invited report

Research and Development of Nanomaterials and Nanotechnologies in Belarus

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Among the priorities of scientific research and developments in the Republic of Belarus the creation of new materials and the technologies of their production, the most important of which are nanomaterials is of special important. The research in this direction in Belarus has been already conducted for quite a long time, but nowadays it parted out into a separate State Complex Program, where Institutes of the NASB, high education establishments as well as organizations from various branches of industry participate.

In the report the results of Belarusian scientists in the sphere of theory, experiment, and practical application of nanomaterials and technologies of their production have been considered. This direction is one of priorities in Belarus [1].

The themes of the researches include development of new principles and models for nanoobjects description, methods of research and diagnostics of systems with small-sized structuring: synthesis and research of new nanosized materials (carbon, refractory, composition in the form of ceramics, polymer, layered and membranous structures) of different purpose, development of devices and systems based on the ones.

Great attention is given to the research of the fundamental mechanisms of formation of nanotubes, powder particles, fullerenes, and processes of structure organization of membranous, layered, bulk nanomaterials of different classes in the conditions of high-energy effect (such as arch discharge, laser radiation, high dynamic and static pressures, mechanical alloying, and obtained by the way of electrochemical precipitation, plasmochemical and self-propagating high-temperature synthesis), regularities of nanodevices and systems, based on nanostructured silicon and alumina, operation; also organic and inorganic molecules.

In the report new methods of obtaining and diagnostics of nanomaterials, their characteristics and spheres of application are considered. The results of research in the sphere of device-equipping Atomic Force Microscope for exact interpretation and data-processing of the results obtained for different nanostructured objects are considered [2].

The properties of composition nanomaterials as well as traditional composites with additions of nanostructured carbon elements are considered.

The examples of application of different classes of nanomaterials in different devices perspective for usage in industry are provided. They are nanoelectronic devices based on the porous silicon, carbon nanotubes and alumina, appliances based on Hall's sensors. In Belarusian State University of Informatics and Radioelectronics experimental samples of microdisplay based on nanostructured silicon had been designed and manufactured for the first time in the world. The use of nanostructures in various sensors seems to be very perspective [3].

Innovational way of development of the Republic of Belarus also includes commercialization of the scientific research. Therefore one of the most actual issues for now is market for nanomaterials and nanotechnologies creation, which has not been formed yet in Belarus. The sooner this problem is solved, the faster the system of scientific results utilization in industry will be created.

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Oral report

High Strength Nanostructured TiNi-Based Shape Memory Alloys and Their Applications

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Our recent complex investigations show that mechanical characteristics of TiNi-based shape memory alloys can be enhanced by using methods of severe plastic deformations (namely high pressure torsion, HPT and equal angular pressing, ECAP). The ECAP-technique allows receiving the bulk nanostructured cylindrical TiNi specimens, 20 mm in diameter and 100 mm in length at different temperatures and strain values (up to a true strain of about 5-10). The long nanostructured roads and wires, up to 0.2 mm in diameter, can be obtained by combination of ECAP and repeated plastic deformation (RPD) with intermediate annealing at temperatures reduced from 700°C down to room temperature. Transmission high resolution electron microscopy X-ray diffraction, measurements of electrical resistivity and magnetic susceptibility were used for investigation of the structural states and phase composition of alloys, their thermostability on annealing and cooling, including in situ experiments for study of thermoelastic martensitic transformations. It was shown that these nanostructured TiNi-based alloys exhibit high strength and ductility, thermoelastic martensitic transformations and related shape memory effects and superelasticity. It is found that unique feature of thermoelastic martenstic transformations in the investigated TiNi-based crystalline alloys is their relatively weak sensibility to different micro-, submicro- and nanosrtuctured states. Thus, TiNi-based alloys have remarkable microstructural states and mechanical properties and there are possibilities for applying them as high strength and ductile shape memory materials. New potential medical and engineering applications of nanostructured TiNi-based alloys for structural and functional using are considered.

Oral report

Commercialization of Nanocrystalline Two-Phase Titanium Alloys Produced by Severe Plastic Deformation

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Microcrystalline processing of titanium alloys to a nanocrystalline (NC) scale provides increasing their strength characteristics, fatigue limit and wear resistance and also decreasing temperature of superplasticity. Due to such changes in their mechanical properties titanium alloys become advanced for commercial implementation in aero-space industry. The present work considers the results of investigations of structure and mechanical properties for NC titanium alloys and makes their analysis in terms of their practical application. Methods of equal channel angular pressing, multi-step forging and rolling have been used for NC structure processing. Semi-finished products of pilot-industrial dimensions such as plates, rings and sheets have been manufactured from titanium alloys using these methods for evaluating their commercial implementation in aero-space industry. Pilot parts from two-phase titanium alloys- billets up to 150 mm in diameter and 230 mm in length, rings up to 300 mm in diameter and 80 mm in thickness, and sheets, 500 mm in width and 1000 mm in length – have been produced. They had a homogeneous microstructure with grain size less than 0.5 μm and uniform mechanical properties in different sections of parts with excellent properties of strength, fatigue limit and superplasticity.

The application of nanomaterials is distinguished by a number of features attributed to temperatures of their exploitation and possible impact loads. A decrease in high temperature properties is naturally expected at high temperatures. In this connection, the application of NC titanium alloys is possible only in cold part of aircraft engines. Alloys in NC condition (after NC structure processing) are characterized by lower ductility that limits their application in components imposed to impact loads. It has been shown that a modified layer applied to the surface of a blade by means of ion implantation and spraying of protective coating allows increasing fatigue limit and wear resistance of articles processed from these materials.

Processing advantages of practical application of NC titanium alloys for producing aero-space articles have been evaluated using methods of superplastic forging and sheet forming. Unlike the conventional processes the production of semi-products from NC titanium alloys is performed in the temperature range several hundreds degrees below that of usually used for producing such ones. This temperature range is rather attractive in terms of developing resource saving technologies. The reduction of deformation temperature by 200-300°C, as compared with the conventionally used temperatures, results in the considerable savings of electric power, furnace consumables, practically eliminates oxidation, and, consequently, expenditures on the elimination of oxidized/alpha layer and the related ecological activities, makes it possible to increase tool life and to decrease machining costs. It can be expected that attained savings are significantly higher than the necessary expenses/the inevitable costs of increasing strains during formation of nanostructured states.

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Oral report

Bioengineering and Machine-Building Application of Carbon Nanocomposite

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The unique properties of carbon nanocomposite and opportunity of the manufacture of the real-sized articles in industrial scales create prerequisite for its application in ad-vanced machinery and medical technics.

Carbon nanocomposite is provided durability of a locking element of heart artificial valves, which should maintain about 40 mln double impacts per one year in chemically active environment of native blood. The resource of non-failure operation of nanocomposite in the given conditions is comparable with life expectancy of the man with a 5-times durability reserve.

Application of carbon nanocomposite allowed improving engineering and economical index of thermonuclear reactors Tokamak of a series T-4, T-3M and T-7 essentially. The carbon nanocomposite diafragm blocked a working body of reactors from hydrogenous plasma with temperature about 100 mln degree in 8000 cycles without destruction. It allowed to reduce 3 times losses of capacity of a plasma cord, to increase 5 times quantity of useful pulses and to lower 20 times intensity of rigid X-ray radiations of reactors.

Carbon nanocomposite serves as an effective antifrictional material for face seals working at high circumferential speeds of rotation and high parameters of working environment in energy-saturated friction units of advanced machinery. Carbon nanocomposite surpasses about 5 times traditional materials in friction coefficient. It does not lose its mechanical properties up to 2000°C.

Antifrictional element of gasodynamical bearings made from carbon nanocomposite has’nt the traces of deterioration after 2000 cycles start-stop at the minimal value of star-ting friction moment. It works well practically with anyone counterbody. Their important advantage is absence of weldability with a metal surface of the shaft at a short-time contact in case of emergency.

Sphere of realization of properties carbon nanocomposite is much more widely considered directions of its technical application.

Oral report

Numerical Simulation of ECAP at Macro and Meso Level

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A variation-difference method of solving continuum mechanics equations in combination with the visco-plastic self-consistent model was put forward to perform numerical simulation of equal-channel angular extrusion (ECAE). The developed DRACON code (VNIIEF, Russia) together VPSC code (LANL, USA) allowed carrying out simulations of ECAE at macro- and meso- level, showing good agreement between experimental and calculated data.

Oral report

Development of the Combined Technology for Producing Long – Sized Nanostructured Ti Semi-Products for Structural Application

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Despite the existing possibility to produce bulk nanostructured billets and obtain required physical and mechanical properties in Ti, production of such billets still remains a problem [1].

An industrial production demanded a new constructional decision unlike the known laboratory based methods. This is connected with a necessity to reduce the volume of waste material and to enhance constancy of properties, processing speed and low costs of products in the conditions of mass production.

Therefore, our investigations were conducted mainly to improve techniques for processing Ti, including regimes of strain and inter-op thermal processing, to develop die-sets, lubricants, efficient routes of processing, etc.

The investigation results are meant for developing process designs and industrial process for producing long-sized Ti (CP Ti Grade2 and CP Ti Grade4) nanosemi-products with constant high properties.

The given scheme presents a combination of deformation methods: severe plastic deformation (including a stage of preliminary structure preparation) and the subsequent hardening operations.

The first stage (SPD) provides a formation of UFG structure in Ti with grain/subgrain size ≅ 500 nm. The feature of the proposed SPD scheme is a combination of operations on forging and ECAP [1]. Such a decision made it possible to reduce the number of ECAP passes up to 2-4, instead of conventionally applied 8, to increase structure homogeneity, to decrease deficient zones at the ends and surface of a billet. As a result of such processing, for example there were achieved the following mechanical properties in CP Ti Grade2: σ_B=740 MPa; $\sigma_{0,2}$=680 MPa; δ = 18%, the strength of which is, for example, about 1,5 times higher than that of the initial Ti.

The proposed method of combined deformation on the stage of SPD provided ductility in a metal, necessary for carrying out further deformation processing and for producing long-sized rods (L=3000 mm) with record mechanical properties.

For this purpose the obtained at SPD stage billets were subjected to a subsequent strengthening treatment that included such main procedures as multi-pass rolling and drawing. Due to the accomplished investigations there were proposed new engineering solutions, which allowed to optimize deformation and temperature treatment regimes [2], the design of a shape forming die-set [3], lubricant and lubricating coatings[4].

The detailed analysis of the various stages of the combined process made it possible to form a rational version of the technology for producing long –sized billets made of CP Ti with length up to 3 m. The testing of the fabricated samples showed that forming of a homogeneous UFG structure in semi-product made of CP Ti Grade2 with the size of alpha grains 100 nm, allowed to obtain the following mechanical characteristics: $\sigma_в \cong 1100$ MPa, $\sigma_{0,2} \cong 1000$ MPa, $\delta \geq 11\%$, and while realization of the technology for producing semi-products made of CP Ti Grade4 with grains size ≅ 150÷200 mm: $\sigma_в \cong 1240$ MPa, $\sigma_{0,2} \cong 1150$ MPa, $\delta \geq 12\%$. Spread in the mechanical properties along a billet was less than ±5%, at that the technology provided reduction of metal waste, constant quality of a fabricated product, reduction of labor intensity and prime cost of a process.

The fabricated semi-products are meant for producing high-loaded constructions, for example, medical implants and also for application in automobile - and aerotechnics as fixing products.

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Oral report

Properties of HPT Processed Al Alloys

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One of the key tasks tackled at the interface between solid-state physics and pressure shaping is the development of novel approaches that would significantly improve the complex of mechanical and operational characteristics of light Al-based alloys widely used in industry. Such approaches as the achievement of high level of mechanical properties in Al alloys by forming ultrafine-grained (UFG) and nanostructured (NS) states, which demonstrate peculiar "non-equillibrium" grain-boundary behavior and tailored phase composition, are exciting much interest in recent years. To date, it is feasible to obtain such structures in metallic materials through realization of various procedures of severe plastic deformation (SPD) [1]. Generally, the procedures of SPD enable to introduce UFG structure with the size of grains/subgrains varying from 1 μm to several tens of nm in bulk Al alloy billets. At that strength, properties of the materials increase by 30-50 %, as compared to coarse-grained analogies subjected to conventional hardening treatments [2-3].

High pressure torsion (HPT) is one of the current SPD techniques allowing the formation of Al alloys with nano-scale grain sizes ($D \leq 100$ nm), as well as effectively controlling their phase composition. In this connection the work gives the results obtained during the investigation of the effect of HPT processing conditions and subsequent thermal treatment on the NS state formation peculiarities as well as on mechanical properties of heat-non-hardenable Al 1570 alloy (Al-5.7Mg-0.32Sc-0.4Mn) and heat-hardenable 6061 alloy (Al-0.9Mg-0.7Si).

Initial alloy billets having the diameter of 20 mm and 1 mm in thickness were subjected to HPT processing under the pressure equal to 6 GPa till the value of shear strain made up ~ 600 [4]. Before HPT, 1570 alloy billets were annealed at 385°C, and the 6061 alloy billets were solution-treated (ST) at 530°C for 1h and quenched into water. Processing of 1570 alloy by HPT was conducted at ambient temperature and at temperatures of 100°C and 200°C. The 6061 alloy billets were processed at ambient temperature, and then subjected to additional artificial aging at temperatures ranging 70-160°C for up to 48 hours.

It is established that HPT processing makes the formation of NS states in the alloys under investigation possible. The microstructure characteristics found in the alloys before and after straining by the methods of transmission electron microscopy (TEM) and X-ray diffraction (XRD) analysis are given in Table 1.

Table 1. Microstructure characteristics of the Al alloys

Alloy	*Treatment*	*D, nm*	*D_{XRD}, nm*	*$<\varepsilon^2>^{1/2}$, %*	*a,* A
1570	Anneal. at 385°C	≥50 μm	-	$0.010^{\pm 0.001}$	$4.0765^{\pm 0.0001}$
	Anneal. + HPT at RT	~ 120	45 ± 6	$0.190^{\pm 0.030}$	$4.0692^{\pm 0.0003}$
	Anneal. + HPT at 100°C	~ 150	75 ± 7	$0.210^{\pm 0.030}$	$4.0682^{\pm 0.0002}$
	Anneal. + HPT at 200°C	~ 210	86 ± 4	$0.040^{\pm 0.002}$	$4.0685^{\pm 0.0001}$
6061	ST at 530°C + aging at 160°C, 12 h. (T6)	≥50 μm	-	$0.010^{\pm 0.008}$	-
	ST + HPT at RT	~ 100	65 ± 3	$0.110^{\pm 0.020}$	$4.0520^{\pm 0.0001}$

The tensile tests performed established that due to the formation of NS structure, the mechanical strength of the Al alloys under investigation can become 2-2.5 times higher. Thus, ultimate tensile strength in the NS 1570 and 6061 alloys reached 950 and 690 MPa, correspondingly (Table 2). At the same time, the Al alloys demonstrate rather high ductility in nanostructured state.

Table 2. Mechanical properties of the Al alloys at ambient temperature

Alloy	*Treatment*	*YS, MPa*	*UTS, MPa*	*El., %*
1570	Anneal. at 385°C	257 ± 13	394 ± 11	17.0 ± 1.0
	Anneal. + HPT at RT	905 ± 31	950 ± 35	4.7 ± 0.3
	Anneal. + HPT at 100°C	865 ± 25	890 ± 18	4.0 ± 0.4
	Anneal. + HPT at 200°C	845 ± 33		-
6061	ST + aging at 160°C, 12 h. (T6)	276 ± 14	365 ± 16	14.0 ± 1.0
	ST + HPT at RT	660 ± 21	690 ± 28	5.5 ± 0.3
	ST + HPT at RT + aging at 160°C, 0.5 h.	565 ± 15	585 ± 21	13.5 ± 1.5
	ST + HPT at RT + aging at 70°C, 48 h	665 ± 28	700 ± 25	15.0 ± 2.0

The specified decrease in strength of the NS 1570 alloy billets with increasing HPT processing temperature (Table 2) is consistent with its microstructure peculiarities (Table 1). The absence of ductility established in the alloy after HPT at 200°C and its insignificant reduction after straining at 100°C is largely conditioned by the segregation of Mg atoms and/or the particles of secondary β-phase (Al_3Mg_2) along the boundaries of the forming grains due to the processes of dynamic aging taking place in the material at strain.

It is shown that the ductility of NS 6061 alloy after HPT can be increased by application of additional thermal treatment, namely artificial aging (Table 2). It is established that effective aging temperature, at which the growth of the NS alloy ductility is not attended by its weakening, is lower than the temperature of aging used during conventional strengthening heat treatment (T6) by ~ 100°C.

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Oral report

Processing Properties of Nano- and Submicrocrystalline Ti-6Al-4V Titanium Alloy

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Method of superplastic forming (SPF), pressure welding (PW) under superplastic conditions and the integral method combining superplastic forming and pressure welding (SPF/PW) are very promising. But their application for processing of titanium alloys is restricted by low life of die tooling and high labor intensity at removing α-case from the surface of processed products. The successful overcoming of all these drawbacks is possible due to the application of decreased processing temperatures, in particular, 760°C [1] instead of 900°C. However, the decrease in temperature within the above identified range and even below it becomes possible only in case of application of a physical effect of "low temperature superplasticity" [2], which is connected with grain refinement from micrometer to a nanometer sizes.

In this respect let us consider the results of full-scale experiments performed in IMSP RAS with bulk nano-, submicrocrystalline and microcrystalline materials.

The experimental studies were performed using processed sheets out of titanium alloy Ti-6Al-4V in three initial states: State A corresponding to the mean grain size 0.2 μm, State B – to the mean grain size 0.4 μm and State C – to the mean grain size 2 μm.

The aim of these studies was to reveal the influence of the mean grain size within the range from 0.2 to 2 μm on the feasibility of joining by pressure welding and the formability of processed sheets under SP deformation conditions.

The deacrese in the mean grain size of Ti-6Al-4V alloy sheets from 0.4 to 0.2 μm allows the decrease of the lower temperature of SPF from 750°C to 600°C and the fabrication of cylindrical samples qualitative in their shape, bending radius and thickness distribution.

Due to joining of processed sheets under normal pressure corresponding to low temperature superplasticity flow stress one can decrease the temperature of solid state welding [3] . The sound solid state joint (SSJ) for Ti-6Al-4V alloy in State A was obtained at 600°C (*Table*). The solid state joint with similar shear strength was obtained in submicrocrystalline alloy (State B) at the temperature 700°C (*Table*).

Table. Shear strength of SSJ at room temperature

Initial state of Ti-6Al-4V alloy sheets; Temperature of pressure welding, ^{o}C	Shear strength of SSJ (τ), MPa
State B; 700	593,7
State B; 650	215,0
State A; 650	599,1
State A; 600	596,5

Thus, the decrease in the mean grain size to nano- and submicrocrystalline sizes allows the application of the effect of “low temperature superplasticity” for processing hollow components out of Ti-6Al-4V alloy by combining superplastic forming (SPF) and pressure welding (PW).

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Guest key-note report

In the Search for New Functional Nanomaterials

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Modern design of advanced nanomaterials is aimed to the search for the ways of restriction of freedom degrees in open complex systems used for preparation of nanoobjects. It is important to consider the following fundamental parameters characterizing the nanosystems: typical size of the constituent elements (1, 10 or 100 nm), dimentionality (0D, 1D, 2D or 3D), ordering the elements as well as functional properties of initial phases modified by nanosize effects. Thus most of nanomaterials can be generally considered as nanostructured materials possessing an ierarchic structure and polyfunctionality. The key direction of such materials preparation is seemed to be the usage of selforganization and selfassembly principles allowing to achieve prompt and effective formation of nanomaterials. It is tnen important to apply different temlates – intermediate objects controlling interactions on a definite structural level thus forcing the elements of a complex system to selforganize themselves. In the present work a high effectiveness of ionic, molecular, complex templates, surfactants, liotropic liquid crystal matrixes is demostrated in the production of nanostructured functional materials. It is found that the application of templates plays a very important and universal role in the processes of nanomaterials formation.

Oral report

Know-How Trade: Open Forum for Trading Science and Technology Ideas and Solutions, Know-How, Patents, and Software

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The purpose of the business is to develop a world wide internet forum for trading science and technology ideas and solutions, know-how, patents, and software. The forum will be developed to provide an opportunity for small business, intellectual property (IP) owners and investors to acquire due diligence and development assistance such as IP analysis, (development and protection) and technical due diligence assistance to the investors, HR and financial needs assistance to the inventors and manufacturing assistance for small and large corporations. The final goal of the business is to develop a universal tool for low risk, low cost and time efficient process for small to large business development from idea to a mature business with an opportunity to select independent service providers.

With ever increasing pressure to introduce the latest technologies into the market place, a world wide Internet Forum for trading technological and intellectual properties is required. Developing a business model around this unique market need enables transactions at all levels of intellectual property, science, and technology to go forward. For example, this forum would present many development and technology ideas and solutions, know-how, process design, trade practices, patents, software, etc. The market need for this forum is enormous and growing because of the extremely short period of time from invention to market place. Traditional methods and techniques for selling and acquiring intellectual property, science, and technology has several problems, such as time, consumption of management resources, contact of willing parties, and the like. The growing market need for an internet based know-how trade forum is demonstrated by the number of efforts in this space, failed and successful.

A successful Internet Forum that specializes in intellectual property, science, and technology can potentially eliminate or at least greatly reduce many problems involved with the transactions of intellectual property, science, and technology. By having an identifiable forum with world wide recognition with minimal cost that offers standard practices, discrete initial inquires and interaction between sellers and buyers, will allow willing buyers and sellers to be able to transact business with lower transaction costs. Additionally, searchable databases of available ideas and/or solutions that are directly accessible for low cost and easy to use to technical experts, managers and decision makers will lower the barrier to enter the market and result in a large worldwide usage. In the future internet base trade of IP will likely become the major business model for know-how transfer.

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