ústav materiálov a mechaniky strojov
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Topics of dissertations

in study field **5.2.26 Materials**, study programme **Progressive materials and material design**, study beginning in academy year **2018/2019**

Topic 1: **Aluminium based composites prepared by powder casting**

Supervisor: **Ing. Martin Balog, PhD.** (martin.balog@savba.sk)

The thesis will focus on the preparation and on the study of aluminum (Al) composite materials produced by novel method of low pressure casting technology of powder mixture into complex castings. As a result of this process, the composite will consist of fine-grained Al (A1050, AlSi, A6061, A5083) matrix reinforced with ceramic particles, or fibres (Al_2O_3, SiC). The Al matrix will be stabilized by nanometric Al_2O_3 particles, guaranteeing favorable mechanical properties, especially at high operating temperatures and stability of the composite. The influence of the technological parameters (temperature, pressure, atmosphere), which fundamentally affects the castability, the microstructure and properties of these composites, will be systematically studied and described. Microstructural observations (SEM, EBSD, HRTEM) will focus on Al oxides, their morphology and crystallinity, grain growth, and matrix/reinforcement interface reaction. The work presupposes the experimental work, modification of experimental devices, the preparation of samples and their complex characterization. The PhD student will describe in detail the technology of sample preparation, microstructure and mechanical and physical properties. The topic of the dissertation is consistent with the project VEGA 2/0114/18.

Topic 2: **The use of SPT (small punch testing) technique for evaluation of the mechanical properties and creep performance of ultra-fine grained Al materials fabricated by powder metallurgy**

Supervisor: **Ing. Martin Balog, PhD.** (martin.balog@savba.sk)

The aim of the theses is evaluation of the mechanical properties and creep performance of ultra-fine grained Al materials fabricated by powder metallurgy (*in-situ* Al-Al_2O_3 metal matrix composites named HITEMAL®) by a new SPT (small punch testing) approach. Based on the achieved results of SPT tests and microstructural characterisation (e.g. SEM, TEM, EBSD, etc.) the effect of distribution, morphology and content of Al_2O_3 phase on mechanical behaviour of HITEMAL® fabricated by various PM methods and using different particle size feedstock Al powders will be determined. It is expected the candidate will master a methodology, including sample preparation, analyse of achieved results and microstructural characterisation. The SPT results will be compared and verified with standard mechanical and creep tests performed in tension. The use of SPT approach for testing of HITEMAL® materials will be assessed.

Topic 3: **Composite panels with aluminum foam skeleton for heat storage**

Supervisor: **Dr. Ing. Jaroslav Jerz** (jaroslav.jerz@savba.sk)

The main objective of the work is to suggest, develop and experimentally verify the physical properties of panels made of composite materials whose skeleton is formed of aluminium foam produced by powder metallurgy for short-term storage of heat obtained from solar collectors for indoor use. Use of accumulated heat in the winter time after sunset, as well as the possibility to store excessive heat accumulated during the hot summer days and its gradual releasing to the surroundings of the building overnight, allows significantly to reduce the cost for maintaining of a good thermal comfort in the interior. Thermal energy will be stored as a latent heat needed for melting of one composite component and released back during its solidification. The second component of the composite panel will be used as a load bearing skeleton and also as a path for optimal heat transfer between this material and skeleton. The scientific work will include suggestion of optimal combination of main composite components and the structure of aluminium foam, while the porous skeleton should possess as high as possible thermal conductivity. The material for heat storage should possess large phase changing latent heat and low volume shrinkage during solidification. The both components shall not react mutually at working temperatures and need to be non toxic, corrosion resistant and non inflammable. The composites will be prepared by infiltration of liquid heat storage component into porous load bearing and conductive skeleton made of aluminium foam. The heat storage performance of the composite will be evaluated by modern methods of thermal analysis, dilatometry and corrosion testing. The results of work will be published in prestigious scientific journals and in cooperation with domestic and foreign industrial partners applied as components for to the storage of heat in interiors of future nearly zero-energy buildings.

Topic 4: **Metal matrix composites with high carbon content: interface**

Supervisor: **Dr. Ing. Jaroslav Kováčik** (jaroslav.kovacik@savba.sk)

The aim of PhD thesis is to study the interface between components of metal matrix composite reinforced with carbon fiber or diamond particles.
Interface is the most important phase of composite materials used for structural applications in space probes (e.g., carbon fiber reinforced magnesium) as well as for functional applications in the cooling of electronic components (diamond powder coupled with silver or copper or aluminium). In the first case, it is necessary to transfer the force from the metal matrix to the fibers and vice versa. In order for this transmission to be effective, this interface must be robust and stable in working temperature range and during mechanical cycling.
For functional diamond / metal matrix composite materials, the interface between the components also has to provide not only the transmission of the force, but it must also provide defined functional physical properties, such as high thermal conductivity that is higher than copper one and low coefficient of thermal expansion at the level of the coefficient of thermal expansion of silicon or GaAs used for the production of electronic chips.
The MMC composites will be prepared by the method of infiltration of liquid metal into the porous sample carbon fiber and diamond. The technological parameters of the production process, especially the temperature and time of infiltration, will be changed. Also the chemical composition of the metal matrix will be changed via adding of various elements in very small amounts depending on which type of carbide-forming reaction at the interface will be investigated. The structure and composition of the interface by electron and transmission electron microscopy will be examined. The effect of the created interface on the mechanical and thermophysical properties of the composite will be measured and evaluated.

Topic 5: **The thermal expansion of magnesium alloys unidirectional fiber composites**

Supervisor: **Mgr. Stanislav Kúdela, PhD.** (stanislav.kudela-ml@savba.sk)

Investigation of thermal expansion of magnesium alloys unidirectional carbon fiber composites. Composite materials will be prepared by the method of pressure infiltration (cycle: vacuum - metal melting - application of inert gas pressure). Magnesium alloys containing a carbide-forming element (Li, Si, Y, Zr, Al) and various types of carbon fibers (T300, GRANOC, K1100) will be used. The interaction between the fiber and matrix will be studied and its effect on the thermal expansion of the composites in the longitudinal and transverse directions, depending on the concentration of the alloying element, the infiltration parameters, the fiber type, the volume fraction and the spatial arrangement of the fibers.

Topic 6: **High entropy alloys for nuclear power engineering**

Supervisor: **Ing. Juraj Lapin, DrSc.** (juraj.lapin@savba.sk)

Extreme operating conditions of new generation of nuclear reactors cooled by helium require development of new materials with unique properties. High entropy alloys (HEA) have been only little explored up to now and represent very promising group of materials for nuclear power engineering. Although information about irradiation resistance of these materials is very limited, the first published results are very promising. On the contrary to classical alloys, the HEA show self-healing behaviour during irradiation. The PhD thesis will be focused on design, preparation and microstructure and mechanical property characterisation of novel HEA.
The PhD student will participate on preparation of Fe-Ni-Mn-Cr-X type of HEA entropy alloys, where X is the fifth main alloying element, using induction melting and casting. Microstructure, chemical composition and phase composition of the prepared alloys will be characterised by optical microscopy, scanning electron microscopy, energy dispersive spectroscopy, wavelength dispersive spectroscopy and X-ray diffraction analysis. Basic mechanical properties of the studied materials will be characterized by tensile testing, compression testing and hardness measurements. The candidate needs to demonstrate laboratory experimental skills, knowledge of materials science, phase diagrams, basic knowledge of experimental methods for microstructure characterisation and mechanical testing of materials as well as English language knowledge.

Topic 7: **Complex concentrated alloys for high temperature structural applications**

Supervisor: **Ing. Juraj Lapin, DrSc.** (juraj.lapin@savba.sk)

The research in the field of structural materials for applications at extreme conditions such as high temperatures, aggressive environment and combined loading conditions is focused on a very perspective group of complex concentrated alloys (CCAs). The CCAs should replace currently used superalloys, which will require beside the design of the basic chemical composition also an extensive research of their high temperature strengthening. PhD thesis will be focused on the design, metallurgical preparation and casting of novel Co-Cr-Fe-Ni-Al-X type of CCA, where X is minor alloying element. The improvement of high-temperature strength will be achieved by an appropriate alloying and precipitation strengthening of disordered solid solution by intermetallic phases.
The PhD student will participate on preparation of CCAs using induction melting and casting. The student will propose alloying of the basic system by minor additions and will study the effect of the selected alloying additions on substitution/precipitation

strengthening processes. Microstructure, chemical composition and phase composition of the alloys will be characterised by optical microscopy, scanning electron microscopy, transmission electron microscopy, energy dispersive spectroscopy, wavelength dispersive spectroscopy and X-ray diffraction analysis. Mechanical properties of the alloys will be studied by tensile testing, compression testing, creep and hardness measurements. The candidate needs to demonstrate laboratory experimental skills, knowledge of materials, phase diagrams, basic knowledge of experimental methods for microstructure characterisation, mechanical testing of materials as well as English language knowledge.

Topic 8: **Complex concentrated alloys prepared by directional solidification**

Supervisor: **Ing. Juraj Lapin, DrSc.** (juraj.lapin@savba.sk)

The energy and transport industries place high demands on structural materials designed for the work under extreme conditions and look for materials that could be superior to conventional alloys. The complex concentrated alloys (CCA) can be considered as very dynamically developing and perspective group of materials for high temperature structural applications. However, an intensive basic research focused on elucidation of strengthening mechanisms operating effectively at high temperature is required. They are located in the central regions of the phase diagrams and contain more coexisting phases, which are used for the strengthening of the disordered solid solution or grain boundaries. The PhD thesis will by focused on directionally sodified CCAs with columnar or single crystal structure strengthened by precipitates of intermetallic phases.
The PhD student will be involved in the preparation of CCAs of CoCrFeNi type with additions of Al, Ti, Nb and Zr which will be strengthened by intermetallic precipitates. The alloy will be prepared by induction melting which will be followed by directional solidification in Bridgman type apparatus. Microstructure, chemical composition and phase composition of the alloys will be characterised by optical microscopy, scanning electron microscopy, transmission electron microscopy, energy dispersive spectroscopy, wavelength dispersive spectroscopy and X-ray diffraction analysis. The candidate needs to demonstrate laboratory experimental skills, knowledge of materials, phase diagrams, basic knowledge of experimental methods for microstructure characterisation, mechanical testing of materials as well as English language knowledge.

Topic 9: **Novel in-situ TiAl matrix composites prepared by casting**

Supervisor: **Ing. Juraj Lapin, DrSc.** (juraj.lapin@savba.sk)

Automotive, aircraft and energy industry require lightweight high-temperature materials as a replacement of currently used superalloys. One of the factors limiting wider applications of intermetallic TiAl-based alloys is their low strength at temperatures above 800 °C. Intermetallic matrix composites may improve the deficiency of these lightweight alloys at high temperatures because of good combination of the properties of intermetallic matrix and reinforcement. Additional strengthening of these in-situ composites can be achieved by a control of microstructure of the matrix and its strengthening by fine secondary precipitates during heat-treatments. The design of novel in-situ composites needs to include their suitability for processing of components by precise casting technology which would accelerate their practical applications. The PhD thesis will be focused on design and processing of novel in-situ composites with intermetallic TiAl based matrix reinforced with MAX phase particles.
The PhD student will participate on the design of new in-situ intermetallic TiAl matrix composites, their metallurgical preparation and centrifugal casting of simple shape components. PhD student will characterize the microstructure and phase composition of the prepared alloys by light microscopy, electron microscopy, energy dispersion spectroscopy, wave dispersion spectroscopy, and X-ray diffraction analysis. The

applicants are required to have experimental skills, knowledge of material science, phase diagrams, basic knowledge of experimental methods of microstructure characterisation, mechanical testing as well as English language knowledge.

Topic 10: **Microstructure and mechanical properties of in-situ TiAl matrix composites reinforced with carbide particles**

Supervisor: **Ing. Juraj Lapin, DrSc.** (juraj.lapin@savba.sk)

Novel in-situ TiAl matrix composites reinforced with primary and secondary carbide particles are very promising for high-temperature structural applications in automotive, aircraft and energy industries. However, very little knowledge exists about their microstructure and mechanical properties at room and high temperatures. In addition, contradictory information has been published about the effect of volume fraction of the reinforcing carbide particles on compressive properties and fracture toughness. The review of the existing literature indicates that there is a gap in knowledge about mechanisms of creep deformation, creep damage and microstructural stability of these novel composites. Therefore, the PhD thesis will be focused on gaining new knowledge to fill the existing gaps about the microstructural stability and mechanical properties of new in-situ intermetallic matrix composites reinforced with carbide particles, which will be designed and prepared by casting technology at the hosting institution.
The PhD student will be involved in the preparation of the in-situ composites for mechanical testing by vacuum induction melting, centrifugal casting and heat treatments. The microstructure and phase composition of the specimens will be characterised by optical microscopy, electron microscopy, energy dispersion spectroscopy, wavelength spectroscopy and X-ray diffraction before and after mechanical testing. Tensile, compression, fracture toughness and creep tests will be performed using special testing equipment. Applicants are required to have experimental skills, knowledge of material science, experimental methods of microstructure evaluation, mechanical testing of materials, numerical modelling as well as English language.

Topic 11: **Study of the possible using of carbon based reinforcement from organic waste for engineering applications**

Supervisor: **Ing. Martin Nosko, PhD.** (martin.nosko@savba.sk)

This work is focused to investigate the possibilities for production of the carbon based reinforcement from organic waste materials for engineering applications with enhanced functional properties. The main aim is to upcycle waste from textile or food industry for manufacturing of the carbon preforms and to use it for the metal matrix composites with improved properties e.g. thermal and electrical conductivity, mechanical properties. The main objective of work is divided to partial aims, which are:

1. Study the potential source of carbon reinforcement based on organic compounds.
   - To verify possible production of carbon based reinforcement material (CBRM) from waste organic precursors.
   - Characterization of the chemical, physical and mechanical properties.

2. Production of metal matrix composites with CBRM.
   - Validation of conventional technologies for manufacturing the metal matrix composites (MMC) with CBRM, e.g. infiltration technologies, direct extrusion, sintering in combination with surface coating.

3. Complex microstructural study and characterization of the physical and mechanical properties of the MMC on the base of CBM.

During the study, student will gather theoretical and practical knowledge in a field of material manufacturing through various manufacturing routes (including stabilization and carbonization of the input material, infiltration technologies, direct extrusion, sintering in combination with surface coating.). After finishing, student will be experienced in microstructural characterization by scanning electron microscopy and transmission microscopy in hand with sample preparation techniques. Moreover, student will gather knowledge in a field of characterization physical and mechanical properties of CBRM. The obtained knowledge can be further used in science or in private companies focused on the manufacturing, characterization and development of new materials for innovative applications. Student will be supported to get scholarship to join research team in Slovakia or abroad.

Topic 12: **The study of the effect of magnesium powders on the properties of the biodegradable materials prepared by powder metallurgy**
(study in Slovak, only)

Supervisor: **Ing. Martin Nosko, PhD.** (martin.nosko@savba.sk)

Dissertation is focused to study an effect of Mg powders on the properties of the bio-degradable materials prepared via powder metallurgy route. Aim is to reveal an effect of high purity Mg powders of various sizes and their subsequent surface-treatment on the microstructure, mechanical and corrosive properties (in vitro) of biodegradable materials. Aim of the work is to understand and to regulate corrosion processes of biodegradable materials in organism leading to design new construction biodegradable material used for wide variety of medical applications.

The work consists of the main four parts:

1. Study of Mg powder coating techniques (e.g. oxidation or nitridation), or powder mixture with alloying element, with subsequent material compaction.
2. Microstructural characterization via light, scanning and transmission microscopy in dependence on Mg powder treatment.
3. Mechanical and corrosion testing of materials.
4. Complex evaluation of the effect of surface treatment on microstructure, mechanical and corrosive properties - design proper biodegradable material used for medical purposes.

During the study, student will gather theoretical and practical knowledge in a field of surface treatment and manufacturing routes (e.g. oxidation, nitridation, direct extrusion). After finishing, student will be experienced in microstructural characterization of materials by scanning electron microscopy in hand with sample preparation techniques. Moreover, student will gather knowledge in mechanical and corrosion testing of materials in in-vivo conditions. The obtained skills can be further used in science or in private companies focused on the manufacturing, characterization and development of new bio-degradable materials. Student will be supported to get scholarship to join research team in Slovakia or abroad.

Topic 13: **Development of PM components with higher density for "high-performance" application in automotive industry**

Supervisor: **Ing. Martin Nosko, PhD.** (martin.nosko@savba.sk)

Aim of dissertation is to develop Fe based PM component with higher density after sintering > 7,1 g/cm^3 for use in high-performance application in automotive industry with improved mechanical properties and with respect to machining of the component and requirement for the die tool. Work is divided into follows parts:

1. Investigation an effect of powders mixtures at different pressures on component density after compaction.
2. Study the effect of sintering conditions on density of PM component in dependence on powder mixture.
3. Microstructural analysis and testing of mechanical properties.
4. Simulation of thermo-mechanical behaviour and design of the tooling materials suitable for compaction at increased compaction forces without damage.

During the study, student will gather theoretical and practical knowledge in a field of powder metallurgy including sintering, FEM simulations, mechanical and thermo-mechanical testing. The microstructural study will be used to find our relations between manufacturing conditions, powder mixture and mechanical properties. Therefore, student will be experienced in microstructural characterization mainly by scanning electron microscopy (including EDS analysis) in hand with sample preparation techniques. The obtained knowledge can be further used in science or in private companies focused on the manufacturing, characterization and development of new materials on only in automotive industry. Student will be supported to get scholarship to join research team in Slovakia or abroad.