Mesomechanical Principles of Form-Stable Composites Development by Nano-Disperse Reinforcement of Metals and Polymers

[1]Sergey Shilko, e-mail: shilko_mpri@mail.ru, [1]YuryPleskachevsky, e-mail: pleskym@mail.ru
[2]Choe H., e-mail: heeman@kookmin.ac.kr, [2]Choi H., e-mail:hyunjoo@kookmin.ac.kr
[1]Metal-Polymer Research Institute named after V.A. Belyi, NASB, Belarus
[2]Kookmin University, Korea

Although various nano-structures have been suggested for metals and polymers, using nano-scale boundaries, nano-precipitants, and second-phase particles, these structures are obtained only under the specific thermodynamic conditions and hence the stability of the structures is extremely low. Composites incorporating thermally stable nano-scale reinforcement have captured a great deal of attention due to their exceptional properties and stable structures. Hence, these composite materialsare necessary for creation of low-weight and reliable structural elements for airspace technology, machine building, defense means, medicine (implants and prosthesis) and so on.

The present study first aims to develop metal-based and polymer-based composites containing various types of nano-scale reinforcement, particularly focusing on the 1) uniform dispersion of each of the reinforcement and the 2) strong interface between the reinforcement and the matrix. Difficulties in homogeneous dispersion of the reinforcement in the matrix, sometimes weak interface due to the poor wettability between the reinforcement and the matrix, and easy destruction of molecular structures of the reinforcement are main obstacles.

The second goal of the study is to explore mechanical behavior of the composites. Predicting dramatic improvement of physical and mechanical performances has so far been reported for real metals or polymers containing nanosized fillers (short fibres and/or particles). However, the mechanism of abnormal strength and deformation characteristics of the nanocomposites has yet to been fully understood. When suchmaterials are processed by the current high-energy methods (pressing, pressing with shear, extruding, molding, etc), non-uniform structure is formed with the significant internal stress resulting in distortion and defects of the structure.

For optimization of technological process and increasing competitiveness of products, it is extremely important to study 1) its local mechanical characteristics by means of modeling and 2) to predict the parameters of composites using the corresponding data for matrix, filler and interface layers as well as geometry of these phases.The known fundamental results also need to be adapted for disperse-reinforcing metallic and polymer materials, particularly with nanosized fillers, with taking into account the interface layer and non-linear behavior of matrix phase and, in some cases, filler one. Also, mesomechanical analysis of deforming and failure of such materials is necessary in search of ways of recycling of the products which have exhausted the resource.

First of all, we aim to develop new composites containing nano-scale reinforcement. There have been a fair number of attempts to disperse nano-scale reinforcement in the metal matrix or in the polymer matrix using a liquid-state or a solid-state technique. It has been demonstrated that coating processes, such as plasma spraying, cold spraying, and thermal spraying, can be used to fabricate bulk composites. However, poor dispersion of CNTs and unfavourable chemical reactions between reinforcement and the matrix materials are crucial problems in the liquid-state techniques. One of the great advantages of a solid-state technique is the relatively low processing temperatures enough to avoid the unexpected reactions and to provide fine microstructures. The powder metallurgy technique involving the ball-milling process has been considered one of the promising routes for mechanical dispersion of nano-scale reinforcement. Metal or polymer powder is blended with nano-scale materials, followed by hot consolidation of the mixture. Friction stir processing based on friction stir welding has been increasingly reported as a solid-state joining and microstructural modification process. Interesting ideas using molecular-level mixing and severe plastic deformation have been suggested to provide a better mechanical performance of the composites.

With this scope, we suggest to develop metal-based and polymer-based composites containing various types of nano-scale reinforcement via solid-state techniques; to examine the effects of the morphology of reinforcement and interface structures between the reinforcement and the matrix on the mechanical properties; to optimize the processing variables to develop the composite with desirable structures and properties.

The materials under consideration are structured as a heterogeneous composites.Nowadays composite materials are usually modelled as a single-phase, usually, elastic medium (continuum) or as a elastic biphasic (matrix and filler) medium. But to predict such important characteristic as form stability, we must take into account the real configuration of the filler's particles, visco-elastic-plastic properties of matrix and filler as well as interface layer influence. Here is the novelty of the suggested theoretical and experimental results:

- to formulate constitutive equations for solid phase under large strains which typical for polymer and elastomer composites;
- to carry out the static mechanical tests to determine model parameters in the wide temperature and velocity range using identification procedure;
- to carry out the dynamic contact indentation to determine visco-elastic characteristics under local non-destructive loading.

Experimental tests should be developed on the micro and macro-scale.In the first case, structural analysis should be developed in order to determine distribution of the various phases in the real materials. Moreover,particularly for micro-mechanical and nano-mechanical properties,the solid phase should also be analysed.On the macro-scale, parameters of phenomenological description should also be determined. Both cases experiment will have to be conducted to verify the developed mathematical models.

The objective of the proposed project is to createadequate mezomechanical description of nano-disperse reinforcement of metals and polymers**.**The combination of mezomechanical description and experimental study would realize next advantages:

- uniform dispersion of nano-scale reinforcement and development of strong interface between reinforcement and the matrix.
- development of bulk composites with desired density.
- creation of analytical and numerical mesomodels of disperse-reinforced materials at elastic and plastic deformation and original experimental methods of mechanical testing of elastic, plastic, viscous and strength parameters of disperse-reinforced materials.
- mesomechanical analysis of disperse-reinforced composites under tension, compression and shear;the experimental study of samples deformation;the comparison of theoretical and experimental results.
- development of models for composites materials with nanosized fillers and prediction of new deformational effects for these materials.

On the initial two steps of the project the first results have been obtained as given below.

To improve the description of dispersed-reinforced composites, the determination of thermal and viscous parameters of polymer matrix is assumed. It's has been shown that using of hypothesis of stability of relaxation activation energy for the polyfluorene in temperature range 10 … 200 ^{0}C allows to obtain a good accuracy of complex dynamic characteristics calculation in more wide frequency range (1…10 Hertz) than in case of Williams-Landell-Ferry's equation.

Updating of Takanayaga's model, allowing one to analyze uniaxial stress state of the dispersed-filled composite in the conditions of the nonlinear deformation caused by hyperelasticity or a plastic flow is proposed. Variants of model for spherical and cubic reinforcing inclusions are considered. In particular, calculation dependences of axial pressure on longitudinal deformation for polymethylmethacrylate, filled with particles of aluminum oxide have been obtained, at temperature 180 ^{0}C and carbon-reinforced plastic based on polytetrafluorethylene at temperature 20 ^{0}C. Results of modeling are compared with experimental curves of a stretching and compression.