# Mechanochemical Synthesis of Composite Materials

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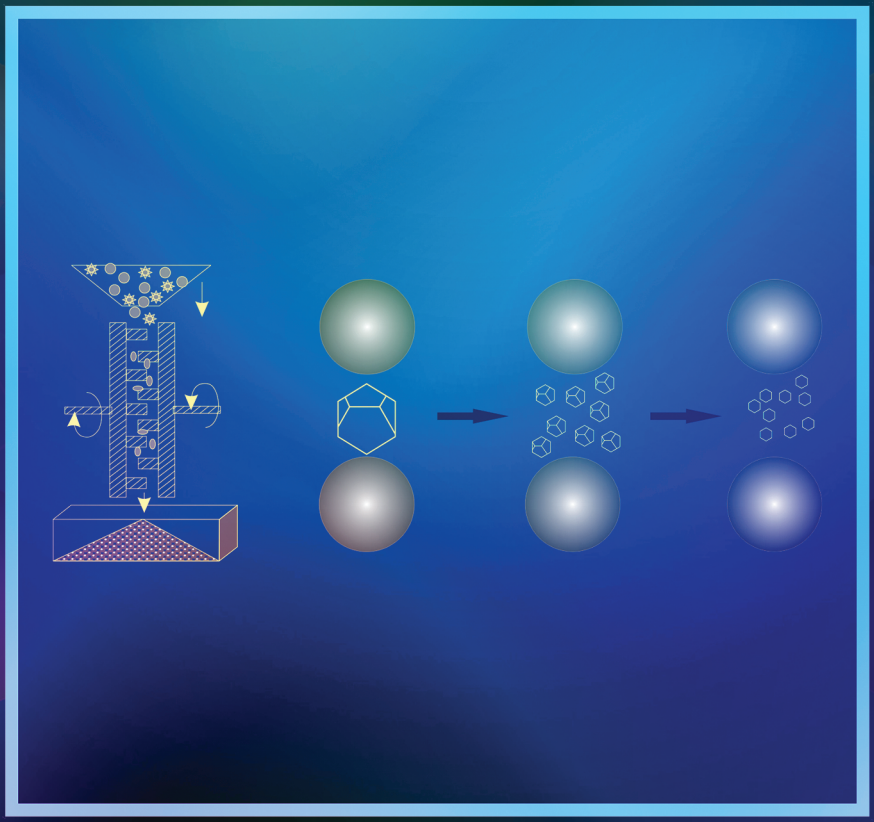

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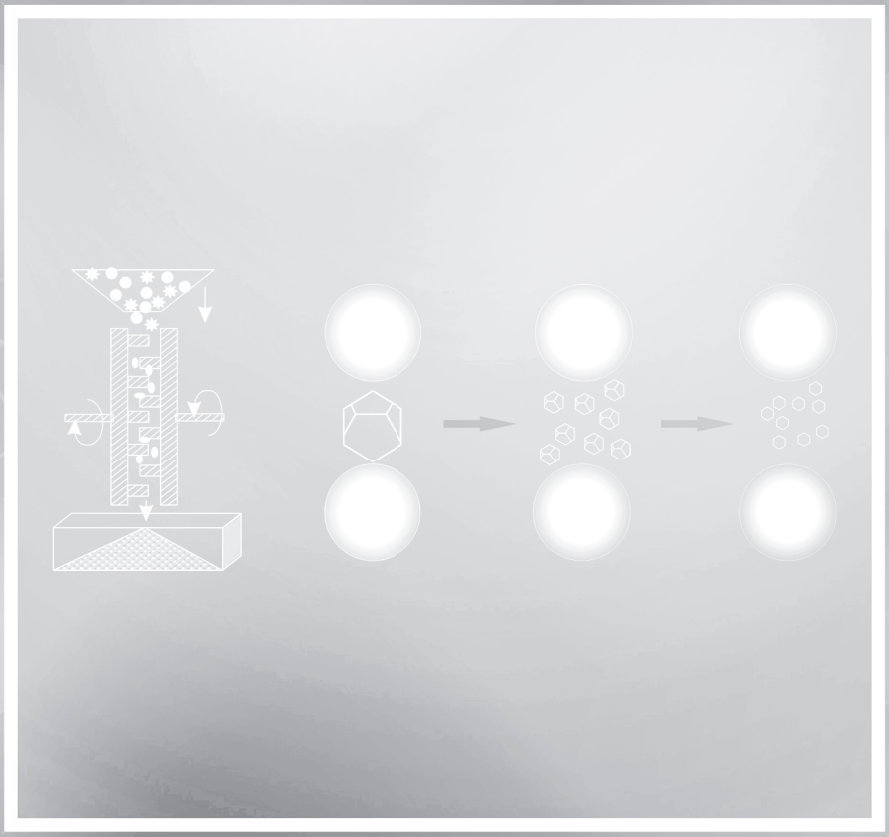

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# Dedication

**Prof. Nina N. Mofa (04.10.1946–16.08.2021)**

Our sorrow today is as intense as our respect and love for Nina N. Mofa. Prof. Mofa lived a bright and worthy life and was a true intellectual, a person of brilliant intellect and great erudition. Since 1988, she worked at the Institute of Combustion Problems in various positions as a senior researcher, chief researcher, and head of the Laboratory of Mechanochemical Processes and Combustion Problems. She actively participated in the scientific and administrative life at the Institute. Her main scientific interest was in the study of the processes of creating nanostructured microcomposite systems by thermal and mechanochemical treatment. She authored more than 300 publications, including scientific articles and abstracts, and 4 monographs and held 28 certificates of authorship and patents of Kazakhstan and Russia. In 2014, she was awarded the badge of the Ministry of Industry and New Technologies of the Republic of Kazakhstan.

The directorate and the staff of the Institute of Combustion Problems express their deep condolences on the departure of Prof. Mofa, the outstanding scientist and unique organizer of science. May the departed soul rest in peace and be a driving force for all of us.

# Contents

# Introduction

Mechanochemical treatment is one of the modern promising directions of the chemical and technological processes of obtaining a new substance as a result of the transformation of mechanical energy into the chemical and physical processes of system restructuring. The peculiarity of the state of solid matter as a result of intensive mechanical action is determined not only by its destruction, i.e., dispersing and obtaining a powder material with a high new and active surface, but also by the accumulation of defects in the entire volume of particles, which increases their reactivity. The increase in the reactivity due to machining is one of the methods for obtaining solids in metastable, active form. In addition, in the process of deformation and destruction of the treated substance, various physical, chemical, optical, electrical, and other phenomena are observed, which, in turn, also affect the processed material. With an appropriate choice of modes of mechanochemical treatment, the material can be brought to the nanodispersed state, thereby increasing the solubility of hardly soluble substances, accelerating chemical reactions, and enhancing the catalytic properties. Much attention has been paid to obtaining alloys in the process of machining, as well as various composite systems.

Synthesis of new inorganic and organic compounds with the use of mechanical action makes it possible to obtain them in the regime of solid-phase processes (reactions) as a result of the large number of contacts between reagents and the possible release of heat in the local contact region, which substantially intensifies the interaction process. A sufficiently large number of scientific articles have been devoted to the problem of dispersion and activation of solid materials of various compositions (mineral systems, nonmetallic and metal compounds, polymer compositions). The results of these studies are summarized in various reviews, monographs, and textbooks. The creation of mechanochemical synthesis of composites, including both

inorganic and organic ingredients, has received much less attention, although the possibilities of the use of such composites in terms of variation in their properties are very large.

This book presents the results of several years' research on the mechanochemical synthesis of composite systems, consisting of inorganic and organic components, obtained by the scientific team of the Institute of Combustion Problems, Kazakhstan. The book first presents the general ideas about the mechanochemical process and the phenomena accompanying it. The main provisions of structural rearrangement and modification of the surface of dispersible particles, as well as thermodynamics of mechanochemical treatment of materials, are then considered. Further, using the example of a number of natural minerals, it is shown how mechanochemical treatment can radically change their structure and properties, using various organic compounds as modifiers. Particular attention is paid to the use of ultrasonic treatment, as a kind of mechanical action in a liquid medium on a solid.

The book has been organized in 10 chapters. Chapter 1 presents the basic concepts and concepts of mechanochemistry and discusses the methods of mechanical action and physicochemical changes of inorganic and organic matter. In Chapter 2, the theoretical foundations of grinding and activation of solids, the main physicochemical processes of substance transformation, the features of structural rearrangement, and the modification of the surface of dispersible particles during mechanochemical treatment are described. The main models of mechanochemical processes are considered. Chapter 3 discusses some issues related to the course of mechanochemical processes, taking into account the shape of a small build and layer thickness, as well as the actual impact of a small build on theoretical and practical positions, which are necessary factors for assessing the quality of the material obtained.

Chapter 4 presents the results of the study of the features of the structural changes in silicon dioxide during mechanochemical treatment, modification, and radical polymerization of the surface of quartz particles, which results in the encapsulation of activated particles. In Chapter 5, the results pertaining to the synthesis of nanocomposite quartz particles encapsulated in carbon-containing shells are considered. The features of the

state, structure, and properties of activated quartz are shown depending on the machining regimes. Particular attention is paid to the question of ferromagnetism of quartz powder induced as a result of mechanochemical treatment. In Chapter 6, the theoretical foundations for the creation of composite nanostructured systems based on quartz by mechanochemical synthesis are presented. The role of the piezoelectric effect of quartz is noted as a component of the process of the particle surface modification by organic compounds. In Chapter 7, the results on the mechanochemical synthesis of dispersed composite systems consisting of mineral particles (quartz, calcite, wollastonite) and a polymer shell are considered. Chapter 8 presents the results of the studies on mechanochemical treatment under the ultrasonic effect on powder systems in an aqueous medium. The role of the cavitation effect and patterns of changes in the structure of properties and modification of quartz, calcite, and wollastonite under the influence of ultrasound as a way of obtaining nanostructured systems are considered. Modeling and quantum chemical calculations of the formation of surface compounds in the mechanochemical synthesis of hybrid powder nanocomposite systems using various modifiers were carried out. Chapter 9 presents the examples of mechanochemical treatment of metal powders, in particular aluminum, to increase their reactivity. For this purpose, organic surfactants are used, which contribute to both grinding and modifying the surface of metal particles. It is shown how, as a result of mechanochemical treatment, structural changes occur both in the bulk and on the surface of metal particles and optimal treatment conditions are established to obtain maximum aluminum activity. In Chapter 10, some areas of application of composite materials obtained with the use of mechanochemical treatment are presented. The results of mechanochemical synthesis of sorbents for water purification from various types of pollution are considered. A method for obtaining magnetic sorbents by mechanochemical treatment of quartz-containing systems for collecting petroleum products from the surface of water is considered. Attention is paid to mechanochemical treatment as a method of preliminary activation and modification of systems designed for self-propagating high-temperature synthesis (SHS) of ceramic materials. The peculiarities

of the influence of mechanochemical treatment and modification of quartz, calcite, and wollastonite in mechanical reactors and ultrasonic treatment on technological combustion of systems and the production of SHS composite systems are considered.

The book summarizes and systematizes the results of a fundamentally new complex approach to the creation of composite polymer-inorganic systems by mechanochemical treatment, both as a result of the traditional approach with the use of dynamic mills (mechanical reactors) and ultrasonic action on powder mixtures. It is shown that by selecting the processing conditions and the composition of the processed systems, composite systems with a nanostructured surface layer of particles can be obtained, which provides a directional change in the properties of the composition.

In addition, the book presents a chapter that focuses on the method of mechanochemical preparation of materials for high-energy systems, which are the most promising, since it allows the most productive management of the formation of new structural compositions that increase the energy intensity of the system. Stabilization of the increased activity of highly dispersed particles is provided by the surface layer modification. This method allows obtaining highly dispersed modified material for various types of fuels, including rocket technology.

*"Modern industry requires advanced materials with increasing demand for better performance. Elaboration of specific compounds with desired technological application is the key process for the progress of both science and technology of materials. In the domain of composites, this book provides the state of the art of the global aspects of the mechanochemical synthesis of composite inorganic, organic, and metallic materials, from basic concepts to practical applications. The well-documented and updated literature is invaluable for researchers, educators, engineers, and, especially, PhD students, as a section of key questions concludes every chapter."*

**Dr. Brahim Elouadi**
**La Rochelle Université, France, and Mohammed-V University, Rabat, Morocco**

Mechanochemical treatment is one of the promising directions of the chemical and technological processes of obtaining a new substance as a result of the transformation of mechanical energy into the chemical-physical processes of system restructuring. The peculiarity of the state of solid matter because of intense mechanical action is determined not only by its destruction, i.e., dispersing and obtaining a powder material with a high and active surface, but also by the accumulation of defects in the entire volume of particles, which increases their reactivity.

This book presents the results of many years of research on the mechanochemical synthesis of composites, consisting of inorganic and organic components, obtained by the scientific team at the Institute of Combustion Problems, Kazakhstan. It begins with the general ideas about the mechanochemical process and the phenomena and further discusses the main provisions of the structural rearrangement and modification of the surface of dispersible particles.

**Zulkhair A. Mansurov** is professor at Al-Farabi Kazakh National University, Kazakhstan, and supervisor of the Institute of Combustion Problems. His scientific work includes the investigation of the kinetics and mechanisms of hydrocarbon combustion, soot formation, nanotechnology, petrochemistry, and carbon nanomaterials. He is the editor-in-chief of *Eurasian Chemico-Technological Journal* (English, indexed at Scopus), *Combustion*, and *Plasma Chemistry*.

**Nina N. Mofa** (04.10.1946–16.08.2021) was head of the Laboratory of Mechanochemical Processes, Institute of Combustion Problems. The focus of the laboratory was the technological development of various inorganic and composite materials both in the powdered form and as shaped products using all types of technological methods, including high-temperature sintering, self-propagating high-temperature synthesis, and mechanochemical synthesis. Prof. Mofa had authored 4 monographs and more than 300 scientific publications.

**Tlek A. Ketegenov** is general director of the Institute of Combustion Problems and professor at al-Farabi Kazakh National University. His research interests are applied mechanochemistry (mechanochemical beneficiation of minerals, production of nanocomposites materials), combustion and explosion processes, issues of metal leaching, and testing of protective polymer coatings.

**Bakhtiyar S. Sadykov** is a senior researcher at the Laboratory of Mechanochemical Processes of the Institute of Combustion Problems and a senior lecturer at the Faculty of Physics and Technology of al-Farabi Kazakh National University. His main scientific interest is focused on the fundamental research on the processes of crushing and mechanical synthesis of new nanostructured compositions.

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