Preface to the special section on mechanochemical synthesis

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This special section of the Journal of Materials Science contains a selection of peer-reviewed original research papers and critical reviews presented at the symposium *Mechanochemical Synthesis and Reactions in Materials Science*, which was part of the Materials Science & Technology 2016 (MS&T16) conference held from October 23–27, in Salt Lake City, Utah (USA). The MS&T Conference series is organized annually in North America by a group of societies including: The American Ceramic Society (ACerS), ASM International (ASM), Association for Iron & Steel Technology (AIST), and The Minerals, Metals & Materials Society (TMS). The symposium devoted to mechanochemical synthesis and reactions attracted 66 contributions from 21 countries. Over four days, the symposium brought together world-class specialists, scholars, and graduate students, who attended 44 oral presentations, including two keynote lectures, and 22 posters, and shared experiences and recent results in a wide variety of topics related to mechanochemistry, from fundamentals to methods,

materials, applications, opportunities, and challenges.

The use of mechanical energy to stimulate physical and chemical processes in the solid state has been long and intensively studied. However, the recent availability of new and more powerful milling devices, abrasion-resistant milling tools, and the advances gained in understanding the fundamentals of mechanochemical processes have revitalized the subject and captured the interest of a growing number of research groups worldwide. Although originally used mostly in solid-state chemistry for preparing metal alloys and intermetallics, dry or liquid-assisted mechanochemical methods are now widely applied for the synthesis of a vast range of inorganic, organic, and organometallic compounds, co-crystals, nanostructures, and composites, to mention but a few. Combined with mineral, and solid-state processing technologies, mechanochemical methods are also highly effective to enhance the kinetics of chemical reactions and are being used in

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fields such as extractive metallurgy and waste treatment, and cement and glass manufacturing. The field is booming, and new opportunities in different areas of research are being continuously explored. Accordingly, the number of related papers published in scholarly journals has grown steadily. This section contains nineteen full-length papers, including five critical reviews, outlining the exciting present and promising future. Dreizin and Schoenitz's comprehensive review highlights recent developments in the milling-induced synthesis of materials with high heat of reaction, the so-called *reactive* and *energetic* materials [1]; these materials are of interest in fields such as explosives and pyrotechnics. The article identifies the challenges, possibilities, and limitations of mechanochemical processing when preparing a wide variety of materials, including intermetallics, thermites, metal-metalloid, and metal-polymer composites. The review written by Streletskii et al. [2] analyzed the role played by both the reactant defect structure and the contact surface area in the reactivity of four mechanically activated *energetic* M/solid oxidant composites (M = Al, Mg; solid oxidants = MoO_3 , polytetrafluoroethylene PTFE). The potentials of using short-term high-energy mechanical milling as a pre-conditioning step in combustion reactions are reviewed by Mukasyan and Rogachev [3]. Interestingly, they show that under certain experimental settings, the microstructure and morphology of the activated reactants obtained by milling do not change during the subsequent combustion reaction; therefore, this hybrid methodology offers the possibility of using mechanical forces in combustion reactions to obtain products with *controlled* microstructures. The contributions of mechanochemical methods to the field of magnetic and magnetocaloric materials are reviewed by Blazquez et al. [4]; the article includes a detailed analysis of the effect of the reactants microstructure, final morphology, and compositional homogeneity of the particles in the magnetocaloric effect. Finally, the last review was written by Baláz et al. [5] and represents a comprehensive account of the history and possibilities of mechanochemical methods in the synthesis of simple and complex chalcogenides. The article also includes some interesting applications in the fields of materials engineering, bioimaging, and cancer treatment and ends with a small section on the possibilities of scaling up the process.

The research areas where mechanochemical methods are being currently applied are broad; therefore, classifying the remaining papers into groups is difficult. There are three articles [6–8] dealing with different materials for hydrogen production and storage. Garroni et al. [6] and Hlova et al. [7] focused on the use of mechanical milling to induce a metathesis or displacement reaction and produce metal hydrides. Garroni et al. [6] showed a fine example of the differences in the reaction pathways of a specific system, when it is either thermally or mechanically activated. Hlova et al. described [7] a novel, quantitative, and solvent-free mechanochemical method to produce alane at room temperature, from a mixture of NaH and AlCl_3 . Huot and Tournant [8] analyzed the effect of ball milling and cold rolling on the hydrogenation sorption properties of a CaNi_5 alloy.

The following group of research papers describes the use of mechanochemical methods for the synthesis and/or modification of different inorganic materials such as powder alloys [9], complex oxides [10], sulfides [11] and silicides [12]. Al-Joubouri and Suryanarayana [9] analyzed the phase formation and microstructural features of five different Fe–Cr–Ni powder mixtures subjected to high-energy mechanical milling. Cepeda-Sánchez et al. [10] described the mechanochemical synthesis, structural peculiarities and oxygen ion conducting properties of the $\text{Gd}_2\text{Hf}_{2-x}\text{Ti}_x\text{O}_7$ system. Baláz et al. [11] analyzed the effect of different experimental parameters on the evolution of Cu:S mixtures when milled in a planetary ball mill to obtain CuS and Cu_2S . Bogala and Reddy [12] analyzed the reaction kinetics of a group of promising thermoelectric materials—metal-doped Mg silicides.

There is another group of articles dealing with the use of mechanical forces in C-containing chemicals. Siddhanti et al. [13] described a methodology to successfully functionalize graphene sheets with fluorine and chlorine atoms in a controlled manner using mechanochemical methods and different halogen sources. Roh et al. [14] compared the effect of two different powder consolidation methods, high-pressure torsion and hot rolling, on the microstructure and mechanical properties of Al/fullerene composite materials. Kim et al. [15] combined chemical and mechanical (ball milling) methods to obtain rGO/Al composite materials and then investigated the effect of the interfacial features on the mechanical and

electrical properties of the resulting material. Wilke et al. [16] carried out an in situ study of the mechanochemical synthesis of a 3D metal phosphonate compound, zinc *N*-(phosphonomethyl)glycinate, proposed the reaction mechanism, and solved its crystal structure.

The last group of papers is concerned with the use of mechanochemical methods in catalysis. Schreyer et al. [17] described how in situ mechanical activation can influence the activity of solids toward heterogeneously catalyzed reactions. Lu et al. [18] obtained and characterized Co/Al₂O₃ catalysts using low- and high-energy mechanical milling and compared the performances of the resulting materials toward the Fischer–Tropsch synthesis. Karcz et al. [19] used electron microscopy to study the relationship between chemical activation and deformation of the chalcopyrite crystal lattice, and the improved leaching kinetics.

On behalf of the organizing committee (Laszlo Takacs (University of Maryland Baltimore County), Suryanarayana Challapalli (University of Central Florida), Jacques Huot (Université du Québec à Trois-Rivières), and myself), I would like to thank all the keynote and invited speakers, session chairs, and participants for their support and efforts in successfully organizing the symposium, with special appreciation to all those authors who have contributed to this special section. Finally, we would like to express our deep appreciation to the reviewers, who by convention, remain anonymous and to Professors Barry Carter and Mark Aindow, who have patiently guided us through the process of getting the manuscripts reviewed and putting together this special section of the JMS.

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