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Editorial

Mechanical Alloying: Processing and Materials

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1. Introduction and Scope

Mechanical alloying is a technique involving the production of alloys and compounds, which permits the development of metastable materials (with amorphous or nanocrystalline microstructure) or the obtention of solid solutions with extended solubility. The elements or compounds to be mix (usually as powders) were introduced in jars, together with a few numbers of balls.

Regarding the scope of this Special Issue, so many options were given to the potential authors:

1. Synthesis and processing in solid-state science and technology: high-energy milling, severe plastic deformation of materials (SPD), reaction milling.
2. New materials/processes: oxide dispersion strengthened (ODS) alloys, nanomaterial, nano-composites, and quasi-crystalline phases/materials.
3. Structural characterization: mechanically induced structural changes in materials (point defects, dislocations, clusters, precipitates, grain boundaries), surfaces and interfaces in activated solids.
4. New equipment and procedures: milling equipment based on improved milling dynamics, processing optimization and milling contamination.

Finally, only height articles have been published. Nevertheless, the set of materials, characterization and applications described in the manuscripts provides a wide spectrum of the potential of this processing technique.

2. Contributions

Regarding the modelling of the milling process, the main problem is due to the high quantity of processing parameters to be controlled, which include the filling factor of the jars, the material of the jars and balls, the milling atmosphere, the milling time, the milling intensity, the ball to powder weight ratio (BPR), the number and diameter of balls, the temperature inside the jars, the local temperature on interactions between powder and balls, the optional change in the sense of the rotation of the jars, the on–off switch periods, the controlled addition of a process control agent (PCA) that can help in grain refinement and act as a surfactant, the frequency of collisions between balls, in which powdered particles are involved, and so on. Thus, it is quite difficult to model the energy or powder transfer during the milling process. Furthermore, there are ball milling devices with different geometries: shaker mills, planetary mills. Likewise, the interaction between of the powders with balls (and/or jar internal wall) can be facilitated by abrasion or percussion. For kinetic energy, the velocity of the balls has a broad distribution. For this, all models are usually based upon estimation. One of the works in this Special Issue applies a non-complex model to compare the final microstructure of two Fe-X-Nb-Cu (X = Nb, Ni-Zr) alloys as a function of the energy transfer in two milling devices: planetary and shaker. In this work, the shaker mill is more energetic [1].

Regarding the production of materials, the alloys and compounds that are produced are obtained in a powder shape. Milling usually favors a reduction in the grain size (except for very ductile materials) and the formation of smooth surfaces with high specific

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surface/volume ratio. The size distribution of the powders can be checked by scanning electron microscopy. One of the problems associated with the milling process is contamination from the milling tools and atmosphere. Additional oxygen contamination can be induced after the extraction of the powders from the jars. Thus, a shift in the composition can be produced. This effect is checked with microanalysis techniques.

Sometimes the powdered compounds can be directly used in specific applications without additional treatments. As an example, Mn–Al-based alloys were introduced in dissolutions with azoic dye. The interaction with the metallic particles favors the decolorization process of the dyes by breaking the azo bond of the macromolecule [2].

In order to obtain an improvement in the functional properties of the alloys and compounds, sometimes controlled annealing is needed. Furthermore, annealing provokes the relaxation of the mechanical induced strain. In one of the articles in this Special Issue, annealing was performed at 700–800 °C in high-nitrogen chromium-manganese steels [3]. The austenite phase of the steel was stabilized. Likewise, the annealing objective is the recrystallization of an amorphous phase [4]. The development of the desired crystallographic phase is associated with the influence of the microstructure in the functional response of the alloy. Some Mn-Co(Fe)-Ge(Si) alloys have a martensitic transformation coupled with a magnetic transition favoring an improved magnetocaloric effect.

Mechanical alloying can be a step-in powder metallurgy process. The powders (as obtained after milling) can be compacted at high pressure. An alternative is the spark plasma sintering process (SPS). Refractory high-entropy alloys are produced to maximize the strength, yield strength and fracture strain [5]. An innovative technique is the microwave sintering of previously compacted powders [6]. Al-Y_2O_3 nanocomposites produced by mechanical alloying and pressing were sintered in a microwave sintering oven. The processing conditions were heating rate of 10 K/min until 550 °C and a dwell time of 30 min. The main objective is to optimize the mechanical properties: hardness, yield strength, ultimate compression strength and compressive strain.

Two of the selected articles are reviews. One is devoted to Fe-Cr based alloys and their consolidation at high temperature [7]. In these materials, the technological objective is to improve the resistance to corrosion. Nanocrystalline alloys have higher resistance than microcrystalline alloys. A system with improved resistance is Fe-Cr-Ni-Zr.

A second article revises the hydrogen absorption behavior and the absorption/desorption kinetics of metal hydrides produced by mechanical alloying [8]. It is a critical overview on the effect of mechanical alloying in binary (CaH_2, MgH_2, etc.) and ternary (Ti-Mn-N and Ca-La-Mg-based systems) hydrides. Sometimes the technological process has multiple steps, involving: mechanical alloying, heat treatment, a second mechanical alloying process, degassing and, finally, extrusion.

3. Conclusions and Outlook

As a main conclusion, it is necessary to acknowledge the variety of alloys and compounds produced by mechanical alloying: Fe-X-B-Cu (X = Nb, NiZr) nanocrystalline alloys, mixtures of the binary Fe-Mn and Fe-Cr alloys with the nitrides CrN (Cr_2N) and Mn_2N, Mn-Al-Co and Mn-Al-Fe alloys, non-equiatomic refractory high entropy alloy $(W_{35}Ta_{35}Mo_{15}Nb_{15})_{95}Ni_5$, nanocrystalline $MnCo_{0.8}Fe_{0.2}Ge_{1-x}Si_x$, nanocrystalline Fe-Cr alloys, Al–Y_2O_3 nanocomposites and hydride-forming alloys. Regarding the study of their properties, it is important to improve mechanical properties, hydrogen absorption, magnetocaloric effect and resistance to corrosion. The processing parameters affect the final microstructure of the material, and the microstructure affects the functional response. Likewise, the powders can be consolidated (press, spark plasma sintering, microwave sintering) to obtain bulk materials. Further investigations should be performed to gain a deeper knowledge of the influence of the milling parameters and to analyze the option to develop new advanced materials for specific applications.

As Guest Editor of this Special Issue, I am very happy with the final result, and hope that the present selected papers will be useful to researchers working on mechanical alloying as processing technique of materials with improved functional properties. I would like to warmly thank the authors of the eight articles in this Special Issue for their contributions, and all of the reviewers for their efforts in ensuring high-quality publications. Finally, thanks also to the editors of *Metals* for their continuous help, and to the *Metals* editorial assistants for the valuable and inexhaustible engagement and support during the preparation of this volume. In particular, my sincere thanks go to Toliver Guo for his help and support.

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