International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-10, Issue-04, July 2024

Comprehensive Review on the Formation of Nanostructures through Mechanical Attrition

Sunder Pal Singh*

Department of Physics, Digambar Jain (P. G.) College, Baraut (Baghpat) – 250611 India (UP)

sunderssss@gmail.com

Abstract: The formation of nanostructures through mechanical attrition has emerged as a pivotal technique in nanotechnology offering unique advantages in terms of simplicity, cost effectiveness and scalability. Over the years, the technique of high-energy milling has evolved, encompassing various forms such as ball milling, attritor milling, and planetary milling. The primary mechanism involves the repeated application of compressive and shear forces, resulting in fracturing and size reduction of materials. Higher milling energy and extended milling times can promote finer grain structures but may also lead to contamination and excessive cold welding. Recent research on nanostructured metallic materials has introduced promising methods for phase engineering at the nanoscale. However, contamination from milling media and the environment can adversely affect the purity and properties of the nanostructures.

Keywords: Nanostructures, Mechanical attrition, Ball milling, Contamination

I. INTRODUCTION

The concept of mechanical attrition dates back to the mid-20th century with the development of mechanical alloying by Benjamin in 1970 which was initially used to produce oxide dispersion-strengthened superalloys [1]. Over the years the technique has evolved encompassing various forms of high-energy milling processes such as ball milling, attritor milling and planetary milling each contributing to the refinement of the methodology and expansion of its applications. The field of nanotechnology has witnessed significant growth over the past few decades, primarily due to the unique properties exhibited by materials at the nanoscale [2]. These properties which include enhanced mechanical strength, chemical reactivity and electrical conductivity differ significantly from those of bulk materials making nanostructures highly desirable for various applications. Mechanical attrition [3] has emerged technique for the synthesis of nanostructures. This technique leverages mechanical energy to induce physical and chemical changes in materials resulting in the formation of nanostructured particles. Surface severe plastic deformation is achieved via mechanical attrition using the technique of surface mechanical attrition treatment (SMAT) [4]. A nanocrystalline surface was successfully generated on LCS using SMAT, with ball sizes varied from 4 mm to 8 mm [5]. The corrosion properties of 316L SS in ASW before and after SMAT were investigated by electrochemical methods, and the microstructures and surface morphologies of the as-received and treated SS samples were determined [6].

II. MECHANISMS OF MECHANICAL ATTRITION

High-Energy Ball Milling: High-energy ball milling [7] is a well-established method for producing nanostructures. The process involves repeated collisions between balls and the material, leading to fracturing, cold welding, and rewelding of powder particles. This continuous mechanical deformation refines the grain size to the nanometer scale. Grinding and Fracturing [8]: The primary mechanism involves the repeated application of compressive and shears forces, causing fracturing and size reduction. Cold Welding: Powder particles undergo cold welding, leading to the formation of larger particles, which are subsequently fractured again. Dynamic Balance: A dynamic balance between fracturing and welding is achieved, resulting in the formation of nanostructured materials.

Severe Plastic Deformation: Severe plastic deformation [9], [10] techniques such as equal channel angular pressing and high pressure torsion induce large strains in materials and refining their grain structures to the nanoscale. In the equal channel angular pressing techniques the material is pressed through a die with an abrupt angle, causing shear deformation without changing the cross-sectional area and in the high pressure method the material is subjected to torsional strain leading to substantial grain refinement.

Properties of Nanostructures Formed by Mechanical Attrition: Nanostructures formed by mechanical attrition exhibit unique properties that differ significantly from their bulk counterparts. Nanostructured materials often exhibit increased hardness and strength due to grain boundary strengthening. Reduced grain size can enhance

 DOI : 10.35291/2454-9150.2024.0306

thermal stability, making these materials suitable for high-temperature applications. Nanostructures can exhibit enhanced magnetic properties beneficial for various technological applications.

III. Factors Influencing Nanostructure Formation

Milling Intensity: Higher milling energy and longer milling times promote finer grain structures but may also lead to contamination and excessive cold welding [11]. Material Properties: The intrinsic properties of the material, such as hardness, melting point, and ductility, significantly influence the efficiency of nanostructure formation [12]. Atmosphere: The milling atmosphere inert gas, vacuum, or reactive gases affects the chemical stability and oxidation state of the milled particles [13].

IV. Applications of Nanostructures

By the help of mechanical attrition the unique properties of nanostructures are suitable for various applications. These are used in electronics for enhancing electrical conductivity and thermal stability make these nanostructures ideal for electronic components. Biocompatible nanostructures can be used for drug delivery and medical implants. High surface area and reactive sites improve catalytic performance in chemical reactions.

Metallic materials typically consist of one or multiple phases, which are homogeneous regions characterized by distinct atomic arrangements. Recent research on nanostructured metallic materials has introduced promising methods for phase engineering at the nanoscale. This involves tailoring phase size and distribution and creating new structures through phase transformation, which allows for precise adjustments in deformation behaviors and electronic structures. Consequently, phase engineering is anticipated to revolutionize the development of materials with enhanced mechanical and functional properties [14]

V. Challenges and Future Directions

Despite the advantages, several challenges must be addressed to fully exploit the potential of nanostructures produced by mechanical attrition. Scaling up the production process while maintaining quality and consistency remains a significant challenge. Contamination from milling media and environment can affect the purity and properties of the nanostructures. Achieving best control over particle size and distribution is important for reproducible properties. Future research should focus on developing advanced milling techniques, better understanding the mechanisms of attrition and exploring new applications for nanostructures. Mechanical attrition faces several challenges, such as contamination, control over particle size distribution, and scalability. Future research should focus on addressing these issues and exploring new material systems and applications.

VI. Conclusion

In conclusion, the formation of nanostructures through mechanical attrition remains a pivotal technique in nanotechnology, offering significant advantages in simplicity, cost-effectiveness, and scalability. High-energy milling processes such as ball milling, attritor milling, and planetary milling have evolved to refine the methodology and expand its applications. The primary mechanism of repeated compressive and shear forces results in fracturing and size reduction, though higher milling energy and extended milling times can also lead to contamination and excessive cold welding. Despite these challenges, recent advancements in phase engineering at the nanoscale and the unique properties of nanostructured materials underscore the importance of continued research and optimization. Addressing issues such as contamination, particle size control, and scalability will be critical in harnessing the full potential of nanostructures for industrial applications.

VII. References

[1] Benjamin, J. S. (1970), Dispersion strengthened superalloys by mechanical alloying. Metallurgical Transactions, 1(10), 2943-2951.

[2] Suryanarayana, C. (1995), Nanocrystalline materials. International Materials Reviews, 40(2), 41-64.

[3] Suryanarayana, C. (2001), Mechanical alloying and milling. Progress in Materials Science, 46(1-2), 1-184.

[4] Temitope Olumide Olugbade, Jian Lu, Literature review on the mechanical properties of materials after surface mechanical attrition treatment (SMAT), Nano Materials Science Volume 2(1), 2020, Pages 3-31.

[5] Singh, S., Pandey, K. K., Bose, S. K., & Keshri, A. K. (2020). Role of surface nanocrystallization on corrosion properties of low carbon steel during surface mechanical attrition.

[6] : Minrui Ran , Ci Zhang , Lei Wen , Hongyu Zhou & Wenyue Zheng (2020): Effect of surface mechanical attrition treatment on stainless steel corrosion, Surface Engineering

[7] Koch, C. C. (1997), Nanostructured Materials, 9(1-8), 13-22.

[8] Ovid'ko, I. A. (2002), Nano-scale ductile mode of fracture in nanocrystalline materials. Acta Materialia, 50(23), 627-640.

[9] Lu, K., & Hansen, N. (2009), Structural refinement and deformation mechanisms in nanostructured metals. Scripta Materialia, 60(12), 1033-1038.

 DOI : 10.35291/2454-9150.2024.0306

[10] Estrin, Y., & Vinogradov, A. (2013), Extreme grain refinement by severe plastic deformation: A wealth of challenging science. Acta Materialia, 61(3), 782-817.

[11] Suryanarayana, C. (2001), "Mechanical alloying and milling." Progress in Materials Science, 46(1-2), 1-184.

[12] Koch, C. C. (1993), The synthesis and structure of nanocrystalline materials produced by mechanical attrition: A review, Nanostructured Materials, 2(2), 109-129.

[13] Benjamin, J. S. (1970), Mechanical alloying, Scientific American, 234(5), 40-48.

[14] Jialun Gu, Fenghui Duan, Sida Liu, Wenhao Cha and Jian Lu, Phase Engineering of Nanostructural Metallic Materials: Classification, Structures, and Applications, Chem. Rev. 2024, 124(3), 1247–1287.

 DOI : 10.35291/2454-9150.2024.0306