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Effects of Milling Time and Temperature on Phase Evolution of AISI 316 Stainless Steel Powder and Subsequent Sintering

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Abstract

In this study, effects of milling conditions on mechanical and microstructural properties of AISI 316 stainless steel powder were examined. Milling process was performed at ambient and cryogenic (-100 to -90℃) temperatures for 1 to 12 hours. The cryogenic tests were performed using liquid nitrogen without direct contact to the main powder. In order to investigate the effect of milling parameters on final properties of sintered samples, hot pressing was performed on selected as-milled powders at 1150 ℃ for 1 hour under 65 MPa pressure. XRD analysis on as-milled powders confirmed the phase transformation of austenite (γ) to α' martensite in all samples. It was also evident from quantitative measurements carried out by Rietveld refinement method that the α' weight fraction was a function of time and temperature. Based on this method, for all phases, crystallite size reduced to nanometer regime. Microstructural analysis for all samples was carried out by Scanning Electron Microscopy (SEM) equipped with Energy Dispersive Spectroscopy (EDS) that confirmed Rietveld analysis results. For as-sintered samples, relative density and Vickers hardness measurement were also performed to assess the physical and mechanical properties.

Key words: AISI 316 stainless steel, nanostructure, cryogenic milling, microstructure, sintering, Rietveld refinement

1- Introduction

Austenitic stainless steels have been the center of attention in various industrial applications such as petrochemistry, implants, and automotive, due to their desired properties especially high ductility, good weld-ability [1–3]. Many attempts have been made in order to improve the strength and wear resistance without sacrificing the toughness [2]. Most of the approaches focus on Severe Plastic Deformation (SPD) techniques such as Equal Channel Angular Pressing (ECAP), High Pressure Torsion (HPT), Accumulative Roll Bonding (ARB), Surface Mechanical Attrition Treatment (SMAT), and Mechanical Milling (MM) [4–10]. In these techniques, grain refinement to sub-micron and nanometer regimes results in improvement of strength and hardness [11,12].

Mechanical milling (MM) has been widely used in Powder Metallurgy (PM). As a typical process, it has become the focal center of interest to achieve desired both equilibrium and non-equilibrium crystalline, quasi-crystalline, and amorphous phases. This process is mainly operated via attrition ball milling, planetary ball milling, multidirectional milling, etc. Among these, attrition ball milling is one of the simplest and perhaps the most cost effective one to synthesize nanostructured materials, with the possibility of large-scale production [13].

Morphology and microstructural evolution after MM significantly depend on milling parameters such as rotating speed (rpm), Ball to Powder Weight Ratio (BPR), Process