Densification Behavior of Fe-Ni Alloy Nanoparticles

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Abstract

The effects of compaction pressure and sintering temperature on the densification of Fe-40wt%Ni alloy nanoparticles were analyzed. The Fe-Ni nanoparticles were fabricated by an arc-discharge method and then, compacted at three different pressures and sintered at 550 to 900 ℃. Densification was completed at temperature as low as 600 ℃ and high-pressure compaction was found to enhance densification. Densification behaviors and microstructure developments have been investigated through density measurements, electron microscopies, and hardness measurements.

Keywords : Densification, Nanocrystalline, Fe-Ni alloy, Compaction

1. Introduction

During last decades, there have been explosive studies on nanoparticles and nanocrystallines but the sintering process by which nanocrystallines are made from nanoparticles has not been studied sufficiently, in particular for metals [1]. Nanocrystalline Fe-Ni alloys are promising soft magnetic materials and, especially, Fe-40wt%Ni Invar alloy can be also used as electrical contact materials [2-3]. This nanocrystalline has been usually manufactured by the mechanical alloying process where agglomerates of nanoparticles are produced instead of isolated nanoparticles [2-3]. In this work, we manufactured Fe-40wt%Ni nanoparticles by an arc-discharge method which produces well-dispersed nanoparticles. Then, we investigated their densification behaviors focusing on the decrease in sintering temperature and the densification enhancement by high-pressure compaction.

2. Experimental and Results

The arc-discharge apparatus produces nanoparticles by evaproting metal melts using electric arc [4]. In this work, Fe-40wt%Ni pre-alloyed ingot was melted at a discharge current of 200A and Ar-50vol%H_2 atmosphere of 1atm. The collected nanoparticles with an average diameter of 100nm were compacted into disk-shaped specimens with pressures of 125, 700, and 1225MPa and sintered at 550, 600, 650, 700, 800, and 900℃ for 1hr. The densities of compacted and sintered specimens were measured using the Archimedes method and the microstructures of nanoparticles and sintered specimens were observed by transmission electron microscopy. The hardnesses of sintered specimens were measured using a Vickers hardness tester.

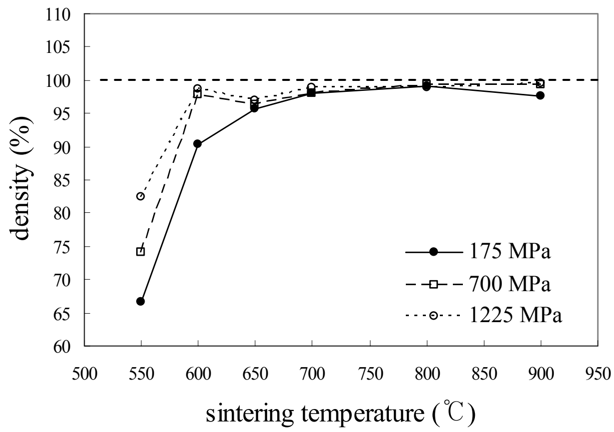

Fig. 1. Densities of Fe-Ni sintered specimens as a function of sintering temperature.

The green densities of the specimens pressed under 175, 700, and 1225MPa were 50, 62, and 67% of the theretical density, respectively. Considering that the green densities of conventional micrometer-sized metal powders are 70 to 90%, it shows that the nanoparticles are not compacted easily. However, their sintered densities reach 90% or higher even at temperature as low as 600℃(Fig. 1) that is almost 400℃ lower than the sintering temperature of conventional Fe-Ni powders. Also, at 600℃, the sintered density increases from 90% to 97% with increasing compaction pressure. The enhanced densification by high-pressure compaction is not a surprising result in traditional powder metallurgy. But, in case of nanoparticles, the oxide layers on the particle surfaces prevents the deformations and the rearrangements of particles so that the high-pressure (>0.5GPa) compaction usually leads a low compaction density and further results in delaminations during a sintering as observed in Fe nanoparticles [4]. Therefore, the present result is opposite to the previous observations and shows that the poor compactibility of nanoparticles depends on the alloy compositions.

The specimen pressed at 175MPa and sintered at 600℃ shows several pores located at triple junctions as shown in Fig. 2(a) as expected from its low density (Fig. 1). However, the specimen pressed at 1225MPa and sintered at the same temperature shows no pores in Fig. 2(b). The specimens sintered at 650℃ shows no pores regardless of compaction pressures. The grains are 200 to 400nm in size, which are two and four times of the initial particle size, respectively. The average grain sizes of the specimens sintered at 600 and 900℃ were measured to be approximately 200 and 500nm, respectively.

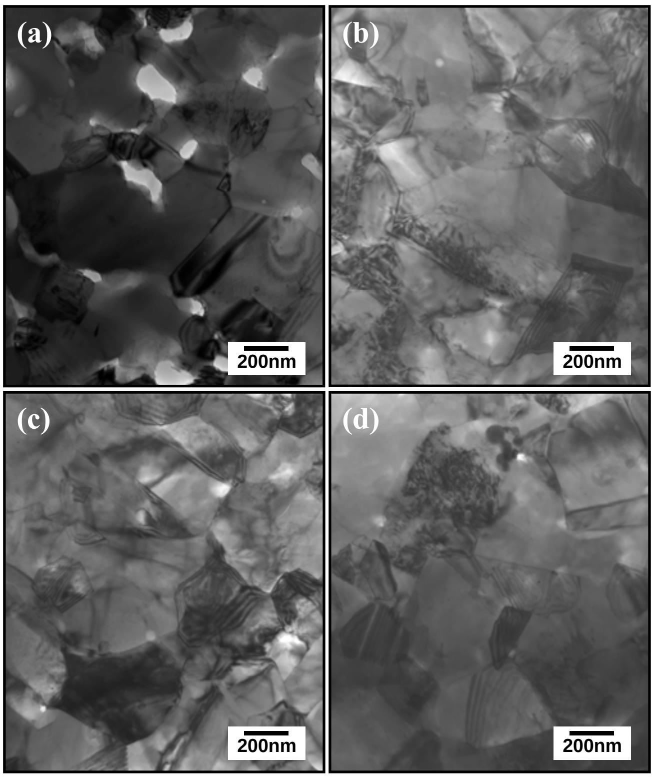

Fig. 2. TEM micrographs showing the microstructures of the specimens sintered at 600℃ ((a), (b)) and 650℃ ((c), (d)) after compaction under pressures of 175MPa ((a), (c)) and 1225MPa ((b), (d)).

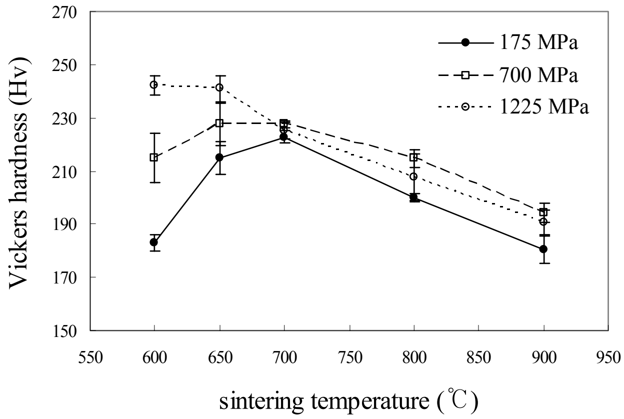

Fig. 3. Vickers hardness of Fe-Ni sintered specimens as a function of sintering temperature.

Interestingly, the hardness data of the sintered specimens shown in Fig. 3 summarize all the characteristics described above. First, its value ranged from 180 to 240Hv is almost twice as high as that of the specimens made from micrometer-sized powders. It illustrates clearly the superior mechanical properties of nanocrystallines over conventional microcrystallines. Secondly, in cases of the specimens pressed at 175 and 700MPa, the hardness increases at first and then decreases with increasing sintering temperature. The increase at a low temperature region is caused by an increase in densities and the decrease at a high one is caused by an increase in grain sizes. This shows that there is an optimum sintering temperature. Thirdly, the maximum hardness of the specimens with the same compaction pressure increases and moves to low sintering temperature with increasing compaction pressure. This shows that high compaction pressure makes densification completed at low temperature where grains grow slowly and so high hardness is obtained.

3. Summary

Fe-40wt%Ni nanocrystallines of high hardnesses were fabricated by sintering nanoparticle compacts at 600℃ that is lower as much as 400℃ than the sintering temperature of micrometer-sized powders. And the densification was enhanced by high-pressure compaction.

4. References

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