PREPARATION AND PROPERTIES OF NANOCRYSTALLINE NICKEL-BASED SOFT MAGNETIC MATERIAL STRIP *VIA* A NOVEL POWDER METALLURGY ROUTE

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Introduction

The high initial and maximum permeabilities, very low coercivity, near-zero magnetostriction and low hysteresis and eddy current losses of Permalloys, containing 75-82 wt% Ni, make them suitable for use as audio coils, transformer laminations, recording heads, and magnetic shields etc. Attempts have been made to synthesize nanocrystalline (NC) Ni-Fe alloy powder around the Permalloy composition by mechanical alloying of elemental powders. Nanocrystalline 80Ni-20Fe (wt %) alloys synthesized by mechanical alloying have shown improved magnetic properties as compared to conventional 80Ni Permalloy [1]. It was also found that the addition of a small amount of cobalt further increased the Curie temperature of nanocrystalline Ni-Fe material and showed a very small hysteresis loss under alternating magnetic field [2]. However, not much work has been carried out to consolidate mechanically alloyed powders to prepare bulk NC material.

Consolidation of mechanically alloyed (MAed) powder into bulk form, wherein retaining nanocrystallinity during consolidation to prepare bulk materials, remains the key issue. In recent years, a few attempts have been made to consolidate mechanically alloyed powders by several methods such as vacuum hot pressing, explosive compaction, hot iso-static pressing, spark plasma sintering, hot extrusion, hot hydrostatic extrusion and several combinations of these methods. All these methods have their merits and demerits.

In the present work, a novel powder metallurgy route for the consolidation of MAed powder into strip shape has been proposed wherein densification is brought about by hot rolling of sintered MAed powder preforms. Most importantly, no sheathing or canning of the powder preforms were carried out before sintering or hot rolling.

Experimental Procedure

The elemental Ni, Fe and Co powder mixtures having composition 80Ni-20Fe (wt %) and 80Ni-15Fe-5Co (wt %) were mechanically alloyed (MAed) using a high energy planetary ball mill. MAed Ni-Fe and Ni–Fe–Co powders were cold compacted, at a pressure of 400MPa, in to rectangular shape green preforms having green density approximately 45% of the theoretical density. The green preforms were sintered and hot rolled at 1140 °C in hydrogen atmosphere. The details of the consolidation procedure are provided elsewhere [3, 4]. The hot rolling was carried out on a specially designed two-high rolling mill interlinked with the soaking furnace in such a manner that the hot preforms remained under protective atmosphere right up to the nip of the mill.

Results and Discussion

Fig.1a shows the variation of grain size with milling time for Ni-Fe and Ni-Fe-Co powder mixture. It can be seen that the rapid grain refinement occurs in the initial 10 hours of milling followed by level off trend. Fig. 1b shows the XRD diffraction patterns of Ni-Fe powder mixture with milling time. It can be seen that the alloying is accomplished after 24 hours of milling as indicated by shifting of Ni peaks towards lower angles. After 46 hours of milling, the average grain size was found to be 10-15 nm, whereas disordered Ni_3Fe was the major phase formed. The total time during processing, at 1140°C, of MAed powder preforms into bulk NC strip was optimized by the study of grain growth kinetics. Fig. 2a shows the grain growth kinetics of MAed Ni-Fe powder at 1140 °C.

It can be seen that grain size of approximately 50 nm is obtained even after 30 minutes of annealing. Therefore, a total processing time of 30 minutes at 1140 ^{o}C was taken in the present work. Fig. 2b shows the grain size of sintered Ni-Fe preforms after every hot rolling pass at 1140 ^{o}C. It can be seen that there was no excessive grain growth during rolling and a total processing time of 30 minutes is capable of producing NC structure in the finished strip. After hot rolling at 1140 ^{o}C, near full density and crack free strips of Ni-Fe and Ni-Fe-Co were obtained. Fig. 3a shows the AFM image of the hot rolled Ni-Fe strip which confirms the presence of nanocrystalline structure in the strip. The grain size in the finished bulk NC strips was found in the range of 30-60 nm. Fig. 3b shows the fracture surface of the finished strip wherein a typical ductile dimpled structure indicates a good interparticle bonding in the strip. Fig. 4 shows the hysteresis curves of the bulk NC 80Ni-20Fe and 80Ni-15Fe-5Co material. The resulting narrow hysteresis loop indicates a very small hysteresis loss in alternating magnetic field.

Conclusions

A novel powder metallurgy route has been proposed and experimented to make bulk NC material in strip form from the MAed NC powder. Green powder preforms of MAed NC Ni-Fe and Ni-Fe-Co powders can be sintered and hot rolled at 1140 ^{o}C in the form of near-full density thin strips having average grain size of approximately 30-60 nm.

References

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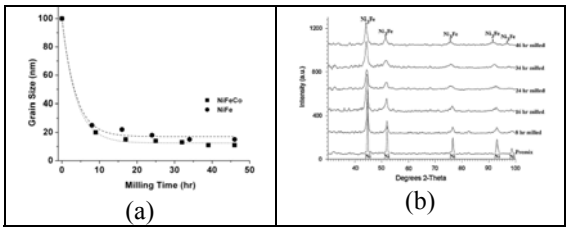
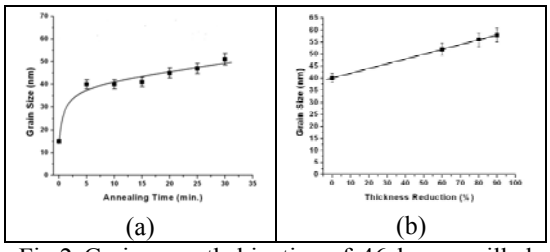


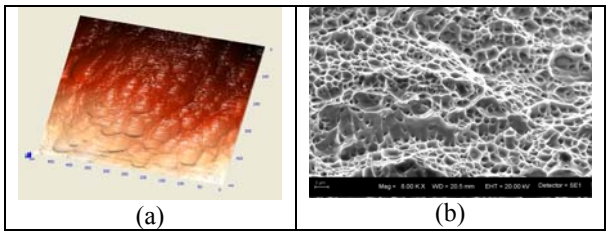
(a) (b)

Fig.1 (a) Grain refinement and (b) phase evolution, during mechanical alloying of Ni-Fe and Ni-Fe-Co powder mixture



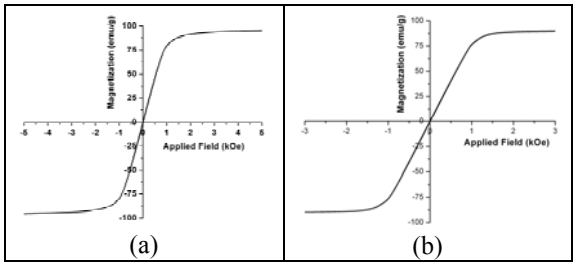
(a) (b)

Fig.2 Grain growth kinetics of 46 hours milled Ni-Fe powder during (a) sintering and (b) hot rolling, at 1140 ^{o}C



(a) (b)

Fig.3 (a) AFM image and (b) fractograph, of bulk NC Ni-Fe strip



(a) (b)

Figure4. Hysteresis curves of bulk NC (a) Ni-Fe (b) Ni-Fe-Co