Bulk FeCo Nanocrystals

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INTRODUCTION

FeCo alloys have magnetic properties which would make for potentially superb power generation applications. This project investigates the possibility of enhancing the mechanic properties of such alloys. The process involves compacting nanocrystalline FeCo powder into solid material using Equal Channel Angular Extrusion (ECAE), while retaining the nanocrystalline grain structure and magnetic properties of the powder.

EXPERIMENTAL PROCEDURE

A mixture of Fe and Co powders was prepared. The mixture was alloyed and the grain size decreased to ~10 nm by milling with steel balls. Approximately 20 g of the resulting powder was poured into a thin copper tube. The tube was placed behind a small copper plug into an extrusion jig in order to increase back-pressure during extrusion. The tube and plug were slowly extruded through the ECAE jig (Figure 1a) at 200ºC. The samples (Figure 2a) were extruded four times through the ECAE jig in order to be better compacted. The resulting solids were inspected for physical and magnetic properties.

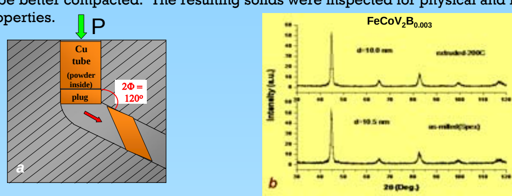

Figure 1:* *a. *Schematic showing the extrusion of a copper tube and plug through an ECAE jig. The tube contains a powder of an alloyed FeCo with nanocrystalline grain size;* ***b.*** *Data from x-ray diffractometer shows that grain size is ~10 nm. The effective grain size, d, was calculated by applying the Scherrer formula:* ***b cos(q) = kl/d***

where k is the Scherrer constant, l is the wavelength, q is the Bragg angle, and b is the full width at half maximum (FWHM) of the samples.

EXPERIMENTAL RESULTS

Sample	Milling	Extruding
1. FeCo 50-50	Szegvari attritor	4 x 90° turns
2. FeCo 50-50	Szegvari attritor	4 x 180° turns
3. $FeCoV_2B_{0.003}$	Szegvari attritor	4 x 90° turns
4. $FeCoV_2B_{0.003}$	Szegvari attritor	5 x 90° turns
5. $FeCoV_2B_{0.003}$	Szegvari attritor	4 x 180° turns, 200°C
6. $FeCoV_2B_{0.003}$	Spex mill	4 x 180° turns, 200°C
7. FeCo 30-70	Spex mill	4 x 90° turns, 200°C
8. FeCo 30-70	Spex, annealed 300°C 3hrs	4 x 180° turns, 200°C
9. Fe	unmilled	4 x 180° turns, 200°C
10. Fe	Spex mill	4 x 180° turns, 200°C
11. Fe	Spex mill/unmilled 50-50	4 x 180° turns, 200°C
12. FeCo 50-50	Spex/Spex+annealed 800°C 2hrs 50-50	4 x 180° turns, 200°C

Table 1. *Information regarding the milling and extruding of all 12 samples.*

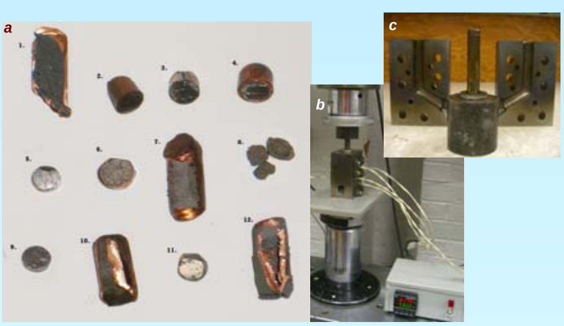

Figure 2:* *a. *The extruded products for all 12 samples. Sample numbers correspond to Table 1;* ***b.*** *Extrusion set up with heaters;* ***c.*** *Extrusion jig and plunger.*

EXPERIMENTAL RESULTS (continued)

The samples were initially extruded at room temperature. The resulting solids from ECAE, however, were brittle. Thus, the temperature was increased to 200ºC in order to soften the powder and facilitate the compaction process.

After several samples had failed to compact into a strong bulk solid, testing was done to investigate whether the milled powder was strain hardened to a point where it would not compact.

Extruded milled and unmilled Fe powders were compared.

The unmilled powder compacted into a strong solid, yet the milled powder did not. **Hence, strain hardening plays a significant role in the compaction process.**

Consequently, a mixture of milled-unmilled 50-50 Fe powder was prepared. This powder compacted successfully.

Extruded powders:	unmilled Fe	50%milled-50%unmilled Fe
Density	86.6%	84.4%
Microhardness	137 HV	218 HV

The microhardness measurements suggest that the addition of nanocrystalline Fe resulted in better mechanical properties.

The magnetic properties of three samples, in their as-milled and extruded states, were determined by the use of a vibrating sample magnetometer (VSM) (Figure 3).

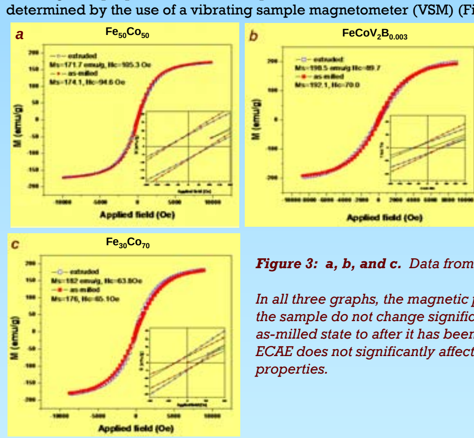

Figure 3:* *a, b, and c. *Data from the VSM*

In all three graphs, the magnetic properties of the sample do not change significantly from its as-milled state to after it has been extruded. ECAE does not significantly affect the magnetic properties.

It is important to note that although some of the samples in Figure 2a appear to have compacted, the photograph may be misleading (Figure 4).

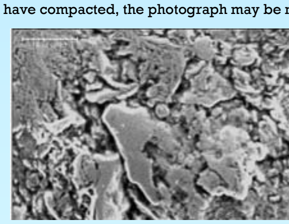

Figure 4. *SEM of $FeCoV_2B_{0.003}$ (Sample 4)*

While the sample seems to have compacted, this SEM photograph at a magnification of x750 reveals that there are many cracks in the extruded sample. This indicates that the density is not as desired, and the sample is likely to break under minimal pressure.

CONCLUSIONS and FUTURE WORK

The extruding process has no significant effect on the magnetic properties of the milled powders, nor does it change the nanocrystalline grain size. ECAE is a process which is very sensitive to strain hardening and oxidation.

Future research may be directed towards the ECAE of powdered mixtures of milled FeCo with unmilled Fe. This may offer a solution to the problem of strain hardening during the milling process.

ACKNOWLEDGEMENTS

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