The effect of mechanical working on the in-plane magnetic properties of Hiperco 50

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Due to its high permeability and low coercivity Hiperco 50 is a premier soft magnetic material. It is often utilized, in laminate form, in rotors for aircraft power generators. These laminates are usually linearly cold rolled from larger billets. The rolling procedure results in the development of specific texture components within the material. This work shows the effect of rolling schedule on the texture of resulting material. Several rolling schedules were considered including straight rolling, cross rolling, clock rolling, and intermediate schedules between these. Varying the rolling schedule has been shown to have a dramatic effect on the resulting texture. In addition, the connection between texture and magnetic anisotropy is explored through a consideration of the angular distribution of easy axes and magnetostrictive strains within the material. This is done through theoretical calculations based on published values of the magnetostrictive and magnetocrystalline anisotropy constants for FeCo. We have observed a strong relationship between the mechanical history of the material and its texture. This implies a strong dependence of the in-plane magnetic properties on the mechanical history. [S0021-8979(99)55208-0]

I. INTRODUCTION

Having the highest magnetic induction of any alloy system,[1] the iron cobalt alloys find use in many applications where high performance is needed or desired. An example of this is an aircraft's power generation system.[2] Here the soft iron cobalt alloys are used as the main constituent in the rotor assembly. Less material is needed in the rotor because the increased induction of these alloys and the assembly can, therefore, be made smaller. This reduces the overall weight of the craft, increasing its efficiency. The iron cobalt alloys are also attractive for this application because of their potential for high temperature use. The current rotor design is part of a unit that is separate from the main engine shaft and has its own cooling system. The iron cobalt alloys present the possibility of further reductions in weight and complexity by permitting the power generation assembly to be mounted directly to the engine shaft without cooling.

The generator assembly consists of a rotor that is rotated in a fixed field. We would therefore desire that the rotor be axially isotropic, giving it a uniform response as it is rotated. However, these parts are generally made from laminations of rolled sheets, and these sheets often possess strongly preferred crystallographic orientation, or texture. This means that there will be a variation in the orientation of the easy axes of the material as a result of the rolling.[3] By connecting the processing and the resulting magnetic properties we can better engineer materials for our application.

II. EXPERIMENT

To measure the effect of different rolling schedules on the magnetic properties of Hiperco 50 we began with nominally 0.080 in. thickness hot band samples obtained from Carpenter Technologies. These samples were then rolled to 80% reduction in thickness varying the direction of the rolling from sample to sample. The first sample was a linear roll that is equivalent to conditions in a conventional rolling mill. Next a sample was cross rolled. This involves alternating the direction between the original roll direction of the hot band and 90° to that direction for every other rolling pass. Finally, a sample was clock rolled by varying the rolling direction similarly to the cross rolled sample except that the roll directions were spaced 22.5° apart and eight passes were made so that the rolling directions made a full 180° sweep of the sample.

III. RESULTS AND DISCUSSION

A. Pole figure analysis

A pole figure is a map of the intensity of a single peak in an x-ray diffraction experiment as a function of angle.[4] This figure allows us to determine multiple deviations from random orientation. In a pole figure, the intensity is reported in terms of a random distribution. This means that, for a truly random sample, we would obtain a pole figure with an intensity of unity everywhere. However, most polycrystalline samples are not truly random. This will lead to intensity variations in the pole figure. These variations can then be used to describe quantitatively the crystallographically orientation of the polycrystal.

Pole figures were measured for the three rolling schedules as well as a sample of the original hot band material. The orientation distributions were measured and then the pole figures were recalculated. The [100] pole figures and discrete orientation plots, used in texture calculation and refinement, were calculated using the popLA software package and are shown in Figs. 1 and 2, respectively. First, we look at the pole figure for the undeformed sample. The intensity in this figure is relatively uniform with little recognizable texture. This is to be expected after the hot rolling treatment.

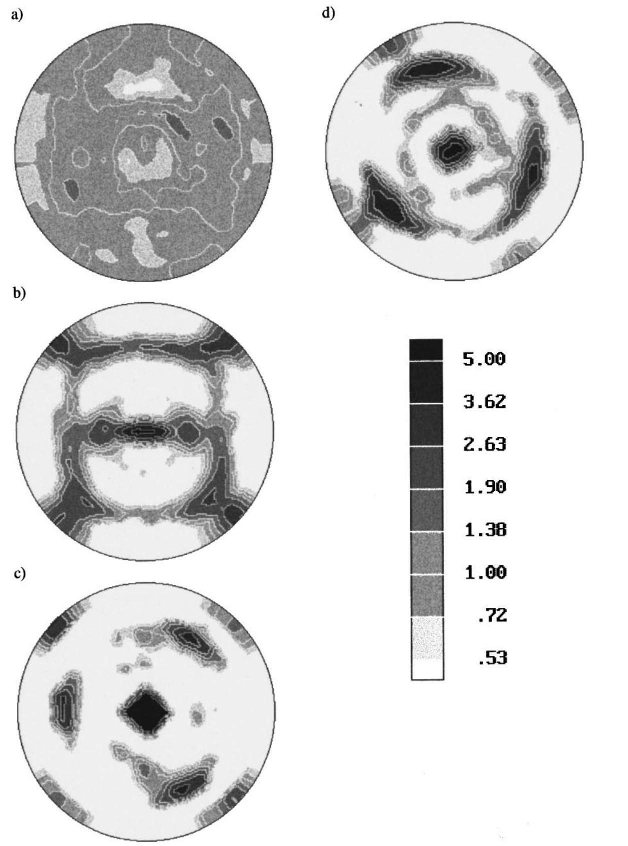

FIG. 1. [100] pole figures for the undeformed (a), conventionally rolled (b), cross rolled (c), and clock rolled (d) samples. Rolling directions is at 12 o'clock in all figures.

This tells us that we are starting with a relatively randomly oriented polycrystalline material before we begin rolling. We conclude that any texture observed after rolling is the result of the deformation and not the initial state of the material.

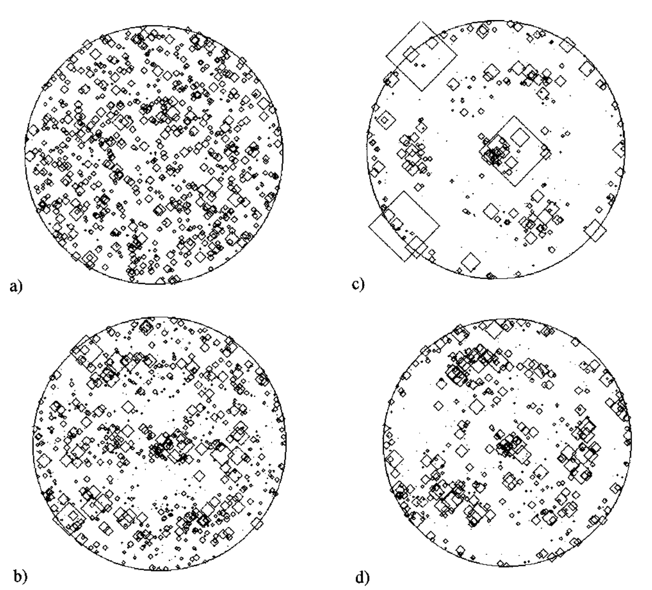

FIG. 2. Discrete orientations describing the texture of the undeformed (a), conventionally rolled (b), cross rolled (c), and clock rolled (d) samples.

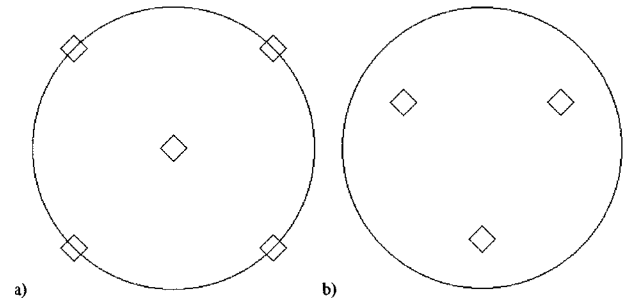

FIG. 3. Single crystal orientations for (a) the {100}[110] and (b) the {111}[110] single crystal orientations. Only one of the variants related through sample symmetry is shown for clarity.

Next, we focus on the conventionally rolled sample. We no longer see the random distribution of grains that was seen in the undeformed sample. Instead, there is a strong {100}[110] component. This means that the ⟨110⟩ directions are aligned with the rolling and transverse directions, but the [001] direction is aligned with the sheet normal. This is a variation of the Goss texture often seen in grain oriented silicon steels. This texture would result in strong peaks in the magnetic anisotropy when measured in the plane of the sheet. This is the reason that when rolled sheets are stacked into laminations the orientations of the sheets are varied relative to the other sheets. This gives an averaging effect and results in a nearly uniform in-plane anisotropy.

The next sample examined was the cross-rolled sample. In this sample, we vary the rolling direction in two orthogonal directions. Instead of uniformly ''smearing'' the texture to produce a more uniform material, we instead see a very strong {100}[110] component and a weaker {111}[110] component. In fact, the rotated cube component is stronger than in the conventional rolling case.

Finally, for the clock-rolled sample, the rolling direction was rotated at 22.5° per pass for a total rotation of 180°. The pole figure from this sample shows the same components as

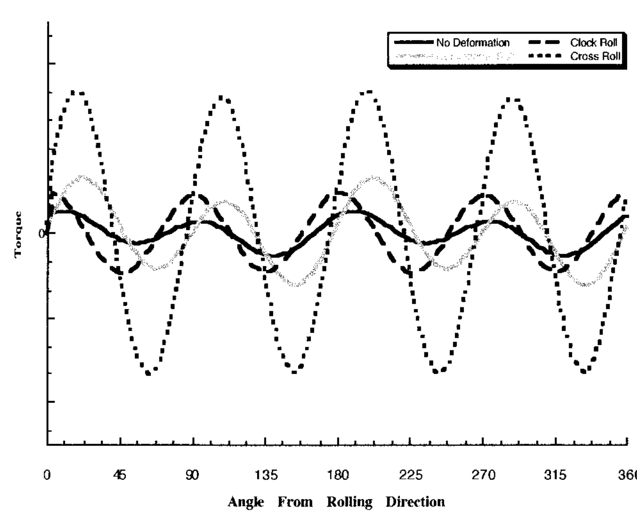

FIG. 4. Predicted torque for various rolling schedules as calculated from discrete crystal orientations.

the cross-rolled sample, but at different relative intensities. In this case, we see a weaker {100}[110] component and a stronger {111}[110] component. We surmise from the analysis of the cross- and clock-rolled samples that the increased number of rolling vectors aids in the rotation of grains from the {100}[110] to the {111}[110] orientation.

We have also investigated the single crystal components and the torques associated with them. The discrete single crystal orientations are shown in Fig. 3. We can see that the dominant texture components present in the rolled samples can be described as ratios of these components. From the discrete distributions we can calculate the magnetic torque in the plane of the sheet for a given material with that distribution. The predicted torques obtained from our experiments are shown in Fig. 4.

From Fig. 4 we can see a number of features of the various rolling schedules. First, the conventionally rolled sample is comparable with that of the undeformed material. From this we can conclude that the conventional rolling process does not greatly affect the magnetic anisotropy. The results are different when we begin to vary the rolling direction. In the case of the clock rolled sample, the texture gives rise to a torque that is comparable to that of the conventionally rolled sample, but we would expect very different mechanical properties. One could envision applications where the mechanical properties afforded by the clock rolling procedure, e.g., creep resistance, would be preferable to those of a conventionally rolled material. For the cross-rolled sample, we can see that the very strong {100}[110] texture gives rise to a strong in-plane anisotropy and hence a strong peak in the predicted torque. This could be a preferable condition for fixed orientation applications where the easy axes of the sheet could be aligned with the applied field.

IV. CONCLUSIONS

It has been shown that the rolling schedule for Hiperco alloys dramatically effects the resulting texture of the sheet. The dominant texture component observed was the ''cube'' {100}[110] texture. In the case of the cross- and clock-rolled samples, the additional deformation vectors appear to allow for the evolution of the {111}[110]. The cross rolling also yields the highest predicted magnetic torque.

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