JOURNAL OF THE PHYSICAL SOCIETY OF JAPAN VOL. 17, SUPPLEMENT B-I, 1962
PROCEEDINGS OF INTERNATIONAL CONFERENCE ON MAGNETISM AND CRYSTALLOGRAPHY, 1961, VOL. I

Magnetic Method for the Determination of the Anisotropy Distribution in Ferromagnetic Powders*,**

P. J. FLANDERS AND S. SHTRIKMAN***

The Franklin Institute Laboratories, Philadelphia, Pa., U.S.A.

A technique for the determination of the anisotropy distribution in a ferromagnetic powder consisting of uniaxial particles is described. The technique which is applicable both to random and oriented samples eliminates, in principle, the effects of incoherent rotations. It involves measurements of the torque versus field with the field applied at a small angle to the remanence, cycled between zero and a maximum field whose value increases on consecutive cycles. An application of this method to γ-Fe_2O_3 powder is described.

Recently three methods have been described for the determination of the anisotropy distribution in ferromagnetic powders consisting of uniaxial[1)] particles. The first, due to Johnson and Brown[2)] is based on remanence measurements. The second due to Berkowitz and Flanders[3)] utilizes the rotational hysteresis. The last one[4)] which is also due to Berkowitz and Flanders uses torque measurements on oriented precipitates with the field applied perpendicular to the direction of orientation.

In essence the procedure in all these methods is the same. One tries to synthesize an observed curve by superposing an assembly of theoretical curves each corresponding to a different anisotropy value. The theoretical curves are calculated assuming that the magnetization reverses coherently in each particle. The reliability of these methods will therefore be impaired in cases in which incoherent reversals[5)] play an important role. Now it has been established both theoretically[6)] and experimentally[7),8)] that the actual reversal mechanism in a uniaxial domain depends, among other things, on the angle between the field and the easy axis, and that it becomes less and less likely for the reversal to be incoherent when this angle approaches $\pi/2$. Accordingly it should be expected that the last of the three methods mentioned above will be more reliable than the other two. In the following it is proposed to present an elaboration of this last method, which enables the examination of samples containing randomly oriented particles. This is an important point as even in nominally oriented materials the orientation generally is far from being perfect. Also the lengthy numerical procedure of obtaining the anisotropy distribution from the measured torque curve is replaced by a simple experimental procedure.

To carry out the necessary measurements the sample is first magnetized to saturation and the field then reduced to zero. The sample is then rotated by a small angle and the torque[9)] versus field, recorded as the field is cycled from zero to H_{max} and back to zero, increasing H_{max} for consecutive cycles. A simple analysis of these curves (shown in Fig. 1) described below yields the anisotropy distribution. Fig. 1 is a plot of torque versus field measured on a random sample of γ-Fe_2O_3 particles.

The reasoning behind this method is explained in Fig. 2. Fig. 2 is a schematic representation for the remanence magnetization. Fig. 2 (a) describes the remanence state of the assembly after the application and removal of the field H. If the sample is then rotated by the angle θ, in two dimensions, only the particles represented by the shaded area in Fig. 2 (b) will contribute to the torque when the field H is applied. Effectively the sample

* The authors gratefully acknowledge the support by the Air Force Office of Scientific Research of the Air Research and Development Command.

** A more detailed account of this study was published by P. J. Flanders and S. Shtrikman: J. Appl. Phys. **33** (1962) 216. See also P. J. Flanders and S. Shtrikman, Proceedings of the 7th Annual Conference on Magnetism and Magnetic Materials, Nov. 1961.

*** On leave of absence from the Weizmann Institute of Science, Rohovoth, Israel.

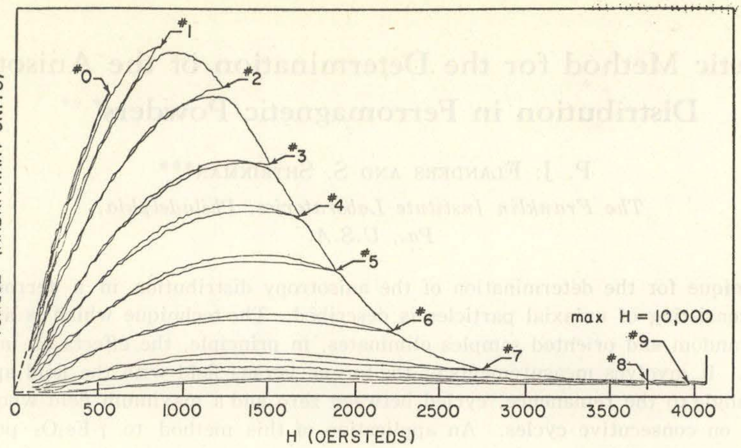

Fig. 1.

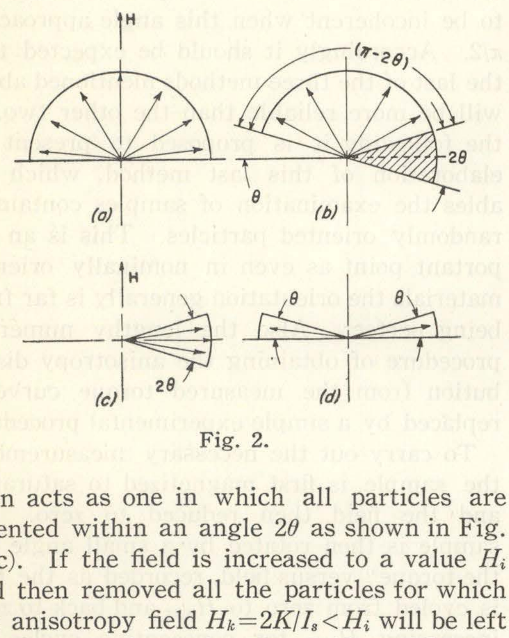

Fig. 2.

then acts as one in which all particles are oriented within an angle 2θ as shown in Fig. 2 (c). If the field is increased to a value H_i and then removed all the particles for which the anisotropy field $H_k=2K/I_s<H_i$ will be left in the state shown in Fig. 2 (d), while the state of all the other particles will not change. (Here K is the anisotropy constant and I_s the saturation magnetization). Therefore the difference in the consecutive torque curves traced with maximum field H_i and H_{i+1} will measure the proportion of material for which $H_i<H_k<H_{i+1}$. Because the area under the theoretical torque curve for a single particle is proportional to the square of the anisotropy field[4], the relative amount of material with $H_i<H_k<H_{i+1}$ will be proportional to the area between the torque curves associated with H_i and H_{i+1} divided by the square of (H_i+H_{i+1}). Using this method a study of the anisotropy distribution in elongated single domain particles of γ-Fe_2O_3 at room temperature was carried out. Following Johnson and Brown[2] the anisotropy has been attributed to particle shape. An average width to length ratio of 1 : 2.4 was obtained from the magnetic data. Electron micrographs show an average elongation of about 1 : 4. The discrepancy might in part be due to interparticle interactions which were neglected in the considerations given above.

References

1 Uniaxial anisotropy of the form $K \sin^2 \alpha$.
2 C. E. Johnson and W. F. Brown, Jr.: J. Appl. Phys. **29** (1958) 313; **29** (1958) 1699; **30** (1959) 136S.
3 A. E. Berkowitz and P. J. Flanders: Franklin Inst. Rept. No. F-2482, 1957. See also reference (5) pp. 160–162.
4 A. E. Berkowitz and P. J. Flanders: Acta Meta. **8** (1960) 823.
5 E. P. Wohlfarth: Advances in Physics, **8** (1959) 87.
6 S. Shtrikman and D. Treves: J. phys. radium **20** (1959) 286.
7 W. Doyle, J. E. Rudisill and S. Shtrikman: Submitted to J. Appl. Phys.
8 K. T. Oguey: Proc. I.R.E., **48** (1960) 1165.
9 A vibrating sample magnetometer might be better than a torque magnetomer which was used.

DISCUSSION

K. HOSELITZ: If the particles are not randomly aligned, is the method still applicable?

Is it not necessary to make a test whether the particles wholly randomly distribute or not?

S. SHTRIKMAN: I don't think that it is right if the sample is not wholly randomly oriented. It is true the absolute value will not be correct, but one gets still effectively reliable relative value since what we do is we normalize the area of distribution to one hundred percent.

L. F. BATES: If you wish to make the test suggested by Dr. Hoselitz, you could punch a hole in the disc specimen, thread a wire through the hole and pass a heavy current down the wire. The disc will then be circularly magnetized in a symmetrical manner.

P. RHODES: How close are the particles to the ellipsoid? How did you estimate the axial ratio?

S. SHTRIKMAN: This is very crude estimate. What we did is looking at the micrograph, taking some reasonable number of particles, measuring the length and width as you see and dividing.

W. F. BROWN: Our method of estimating axial ratios from electron micrograph was also very crude. It is desirable to do a better job, by systematic statistical analysis of observations of many particles. This would be laborious. It also requires considerable study of the basic statistical problem: What is the proper type of statistical distribution for the three axes of the ellipsoid magnetically equivalent to a particle?