PLAINTIFF'S EXHIBIT

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The Magnetic Content of Asbestos by Magnetic Separation

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MAGNETITE occurs as an impurity in most deposits of chrysotile asbestos, particularly the important ones in Canada. This magnetic iron oxide is present in addition to the iron which is substituted for magnesium in the crystal structure. It is a great disadvantage in fiber to be used for electrical applications, primarily because it is electrically conducting and tends to provide a path for breakdown through the insulating barrier which the asbestos is supposed to provide. It is the largest of such particles which are the most likely to provide such a path, being able to bridge more of the thickness of the barrier. To evaluate the quality of asbestos fiber for electrical applications, it would be desirable, therefore, to know the number of particles of the various sizes present. However, the magnetite particles adhere tenaciously to the fibers; and it has not been found practical to make a particle size analysis as a routine test of fiber, although it has been done occasionally. Instead, it is usual to depend on some measure of the quantity of iron present.

A chemical analysis of the quantity of all forms of iron may be used, but it must be corrected for the amount of iron in the asbestos crystal. This amount may vary from fiber to fiber and the degree of error in the method. The magnetic rating test is also widely used (1). It depends on the magnetic effect of the magnetite. As it ignores the iron in the crystal, it is more nearly related to the quantity desired. Unfortunately, there is not a one-to-one correspondence between the magnetic rating and the quantity of magnetite, and a more straightforward test would be desirable. Because magnetic forces are fairly easily applied, many people have tried to make a direct separation of magnetite. It is easy to separate a considerable portion of magnetite in this fashion, but it has been found too difficult to remove the last traces to provide an accurate test. With the advent of more effective permanent magnets, efforts of this type became easier than with the old electromagnets, so it was decided to make another try with them. There is another reason for attempting such an extraction in connection with an extension of the magnetic rating test.

In the magnetic rating test, 10 gms of fiber are placed in an inductance coil which forms one arm of a balanced inductance bridge. Either the change in a standard inductor required to rebalance the bridge or the degree of unbalance of the bridge as indicated by a galvanometer can be used as a measure of the magnetic rating. Before use, the standard inductor or the galvanometer is calibrated with a standard sample of magnetite to make the instrument direct reading. Instruments of this type are described in an ASTM method (2).

The change of inductance on inserting the sample and, therefore the magnetic rating depends on several factors in addition to the quantity of magnetite: its permeability and the size, shape and orientation of the particles. The effects of these latter factors are surprisingly large. For example, the magnetic rating of an asbestos paper will change by about 40 per cent depending on whether the paper is rolled up in the sample holder with the magnetic field parallel to the plane of the sheet or is cut into small pieces and placed into the holder so the field is perpendicular to the sheet. (The paper-making process tends to place elongated particles, the usual form of magnetite, in the plane of the sheet. Therefore, with the cut pieces, almost no particles are parallel to the magnetic field and a low value for magnetic rating results.) It is convenient to describe the combined effect of these factors by the term "relative permeability." The relative permeability is increased if the actual permeability is large or if the particles are large, elongated or aligned parallel to the magnetic field (1, 3, 4).

Recognizing the importance of the difference between magnetic rating and magnetite content, Johns-Manville long ago developed an extension of the procedure to provide an estimate of the relative permeability. A comparison sample of the magnetite in the specimen was extracted with an electromagnet. The extract was repeatedly ground with a mortar and pestle to free the magnetite from the fiber. This, of course, broke up some of the particles, in part vitiating the effort by reducing the relative permeability. The procedure was also very time consuming. Therefore, another incentive to improved magnetite extraction was to provide a better way of obtaining the comparison sample needed to convert magnetic rating to magnetite content.

An apparatus was designed to provide a strong magnetic field over a large area so fiber could be exposed to it efficiently. It consists of a plastic vessel 6 in. in diameter and 12 in. high, around which can be placed a brass frame supporting 17 Alnico magnets. The magnets are in the form of channels, 6 in. long, with sides of opposite magnetic polarity. They form a snug-fitting ring around the vessel, surrounding the lower 6 in. of it, and present to it a succession of alternately north and south poles, approximately equally spaced around its periphery. Magnetic particles in an aqueous slurry tend to adhere to the walls opposite the spaces between these poles. When the separation is deemed adequate, the slurry can be drained through a hole in the bottom of the vessel. Then the vessel is lifted out of the ring of

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Figure 1.—Apparatus for magnetic separation.

Figure 2.—Magnetic extraction procedure.

magnets, and the magnetic material is washed from the walls into a beaker.

In use, 20 gms of fiber are dispersed in two liters of water and are brought into the magnetic field at the wall by stirring with a wooden rod. Both the magnetite and fiber fractions are recycled through the separator according to the schedule in Figure 2. The final dry product is weighed and the value obtained divided by the original 20 gms is taken to be the magnetite content *in* per cent.

It soon became apparent that some further agitation was needed to separate the magnetite from the nonmagnetic material. The size of fiber clumps and rock particles which were adhered to insignificant particles of magnetite attested to the strength of the magnetic field provided. Treatment in a Waring Blendor at full speed for 1 minute was found to increase the yield greatly and seemed to leave the magnetite particles relatively intact, as there was no change in the magnetic rating reading of magnetite concentrate before and after the treatment. This was made a regular part of the process.

A series of fibers of Grade 5 through 7 were separated by this technique. The results are plotted against magnetic rating in Figure 3. Magnetic rating was used as a readily available criterion, not because it was considered to be a especially good one. The early results

Figure 3.—Magnetic extract versus magnetic rating.

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were very encouraging with values nearly equal to the magnetic rating. This was the case with all the 5 grade fibers, and all but 2 of the 6 grade. However, several 7 grade fibers gave enormously large magnetic extracts, more than double the value expected from the magnetic rating of the fiber. By the time the study was completed, it was apparent that the high values did not come from a distinct class of freak fibers, but that there was a continuous gradation from those whose magnetic extracts were essentially equal to their magnetic ratings. The errors in the separation are of two kinds: some magnetite from the fiber sample is lost and does not end up in the magnetite fraction; and there is some material other than magnetite, principally fiber and serpentine rock, in the magnetite fraction. Because of the sources of variation in magnetic rating which are included in the concept of relative permeability, at least some of the dispersion of the results is caused by differences of magnetic rating and not by inadequacies of the separation. Information about the error in both tests can be gained by a chemical analysis of the magnetic extract and by the extension to the magnetic rating test previously mentioned. A chemical analysis is more effective here than for the original fiber because in the magnetic extract the fibrous portion has been greatly reduced and the error in the correction for iron in the crystal structure is not serious. The actual magnetite in the specimen is estimated as follows.

In the magnetic rating test, a fiber specimen with magnetite content, MC, and a relative permeability, μ_r, will have a magnetic rating, MR, given by the following relation:

$$MR = \mu_r MC \quad \ldots\ldots\ldots\ldots (1)$$

This relation is essentially a definition of relative permeability. The magnetite content of the 10 gm specimen, in terms of the weight of magnetite, Q, is:

$$MC = 100 \times Q/10 = 10\,Q$$

In times of Q, the magnetic rating is

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However, the value indicated by the magnetic rating apparatus does not depend on there being 10 gm of material present, but only on the quantity of magnetite and its relative permeability. Because the term "magnetic rating" carries the implication of a measure of the per cent magnetite contained in a 10 gm sample, the term "MR reading" is used to designate the reading of the apparatus when any other sample is introduced. Its value is unaffected by inert materials which may be present and is:

$$MR = 10\mu_r Q \quad \ldots\ldots\ldots\ldots (2)$$

This equation is used to find the relative permeability of the fiber from the MR reading of the magnetite fraction, using for Q the weight of the magnetite fraction corrected for the nonmagnetite material in it. The magnetite content is then calculated from the relative permeability and the magnetic rating of the original fiber by Equation 1.

This analysis was made on a new series of 13 fibers covering most of the range of the early study but with more of the ones which gave a large magnetite extract. The results are shown in Table I.

The fact that the relative permeability is greater than one for most fibers means that the magnetite in those samples has a greater magnetic effect than the standard used to calibrate the apparatus, probably because the particles are larger and more elongated. Relative permeability is also a measure of the effectiveness of magnetic rating as an estimate of magnetite content, it being the ratio of the two. It can be seen that it is not any too precise.

The chemical analysis shows that the extracted material is only about 70 per cent magnetite for "normal" fibers, considerably less, down to about 45 per cent for fibers which yield an abnormally high amount of extract. The process is somewhat better with regard to loss of magnetite, 80-95 per cent of the total in the fiber ends up in the magnetic extract.

A question which naturally arises is: How much better would the separation be if more effort were expended in loosening the magnetite

TABLE I

CALCULATION OF MAGNETITE CONTENT MC AND ACCURACY OF ESTIMATES

Fiber Grade	Magnetic Extract: Fiber MR	Total Wt., MC'	Chem. Anal. % Mag	MR Rdg	Actual Mag. Q	Rel. Perm. μ_r	Calc. MC	MC'/MC	% Mag Extracted Q/MC
4T	2.3	2.70	70	2.05	1.89	1.09	2.11	1.29	90
5K	2.45	2.80	70	2.15	1.96	1.10	2.23	1.26	88
5M	4.15	4.05	70	3.3	2.84	1.16	3.58	1.13	79
5R	3.8	3.55	78	3.1	2.73	1.14	3.33	1.07	82
6D	3.65	4.15	70	3.3	2.91	1.13	3.23	1.29	90
6D	4.0	6.90	52	3.25	3.59	.91	4.40	1.57	82
7D	3.8	4.10	70	3.6	2.87	1.26	3.02	1.38	95
7M	4.4	10.50	45	4.10	4.73	0.87	5.06	2.08	94
7M	3.4	5.00	68	3.0	3.40	0.88	3.86	1.30	88
7RF	2.45	2.85	69	2.2	1.97	1.16	2.11	1.35	93
7R	2.8	3.40	61	2.35	2.07	1.14	2.46	1.38	84
7RF	5.25	7.05	62	4.55	4.37	1.04	5.05	1.40	87
7T	4.0	5.20	63	3.35	3.28	1.02	3.92	1.33	84

$Q = (\%\ mag) \times MC'$ $\qquad \mu_r = MR\ rdg./Q$ $\qquad \overline{MC} = MR/\mu_r$

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TABLE II

EFFECT OF ADDITIONAL TIME IN WARING BLENDER

FIBER GRADE	MAGNETIC EXTRACT			
	TOTAL WEIGHT MC	CHEM. ANAL. % MAG.	MR READING	ACTUAL MAG., Q
6D				
1 min.	6.80	50	3.5	3.40
15 min.	6.35	60	3.4	3.21
7R				
1 min.	3.70	62	2.7	2.29
15 min.	3.20	69	2.65	2.21
7RF				
1 min.	7.05	63	6.0	4.44
15 min.	6.00	71	5.15	4.26

from the fiber and rock? Three samples were beaten in the Waring Blendor for 15 minutes at full speed, instead of the usual 1 minute. The results are shown in Table II. Additional blending time does remove a significantly greater quantity of magnetite, but not enough more so that any reasonable time is likely to make the method satisfactory.

Conclusions

There are many Canadian fibers for which the magnetic separation yields an estimate of the magnetite content which is just about as good as the magnetic rating. However, there are a few, mostly 7 grade fibers, which give an estimate which is far too high. There is, of course, no way of knowing these a priori, so the estimate by direct separation alone does not seem to be a likely candidate for a practical test.

The extended magnetic rating method, with a comparison sample obtained by magnetic extraction and corrected by chemical analysis, offers a way of estimating the magnetite content which is accurate in principle but is time consuming. We have no more reliable way to check it, although this might be done by fiber dispersion.

Taking the extended method results as the standard shows that the conventional magnetic rating test is good for many fibers, but it may lead to errors of the order of 25 per cent. The error is largest for the fibers that cannot be tested by the magnetic separation method, but it is not nearly as great as for that test.

The reason that the magnetic separation does not work for some fibers is suggested by a microscopic examination of the extract. The magnetite particles are found to occur entirely encased by serpentine rock. Anything short of a very tedious grinding operation would not free the magnetite and even then some would almost certainly be lost, going into the fiber fraction.

The most promising feature of this separation technique is that it seems to offer a fairly easy way of obtaining samples of the larger particles of magnetite within the fiber sample. As these are the ones which are of greatest interest, our next efforts will be devoted toward analysis of the particle size of separated fractions.

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