

R & D REPORT

DOW CHEMICAL U.S.A.

RESTRICTED: for use within The Dow Chemical Company only.

DEPARTMENT
Central Laboratory - Texas Division

CRI NUMBER

LABORATORY REPORT CODE

TC-505

DATE ISSUED

October 1, 1974

LAB. NO.

PROBLEM NO.

TITLE
A Critical Evaluation of Current Analytical Methods for the
Determination of Chrysotile Asbestos

14

PAGES
IN FULL
REPORT

PLAINTIFF'S EXHIBIT

DOW-2100

AUTHOR(S)
S. I. Foster

AUTHOR(S) SIGNATURE(S)

REVIEWER'S SIGNATURE

This
report
is:

☒ INTERIM

☐ FINAL

and mainly:

☐ NEW

☒ REVIEW

DESCRIPTIVE SUMMARY
WITH CONCLUSIONS:

(Include in this space references to data books, and to earlier related reports, patents and publications.)

This report outlines known analytical procedures for chrysotile (serpentine) asbestos fibers in various aqueous waste streams. Some of the topics covered are: Electron and Optical microscopy, chemical methods, infrared, ESCA, DTA, X-ray diffraction, etc. A bibliography of papers relating to currently used analytical procedures is included.

The conclusions drawn from this review indicate that TEM (Transmission Electron Microscopy) is the one technique which fulfills all present analytical needs (i. e. identification, counting, and sizing). However, due to the complexity of the method and the cost of instrumentation, a rapid survey analysis which could give an order of magnitude of asbestos concentration and could be implemented into a production facility is needed. The techniques discussed here, specifically, atomic absorption, I. R. , light-scattering, ESCA, adsorption of dyes and tracers, and other chemical methods are being further evaluated as rapid scanning procedures and recommendations will be forthcoming.

DISTRIBUTION:

DEPARTMENT FILES
R & D ADMINISTRATION
CENTRAL REPORT INDEX - 5 COPIES
(566 Bldg. - Midland)

Distribution list
is continued on
attached page.

ST0463856

ST0463856

DISTRIBUTION

Western

M. D. Yeaman
*R. J. Moore

Oyster Creek

*D. A. Rikard
W. H. Caines

Texas

*L. C. Jones, B-1402 Bldg.
F. W. Spillers, B-2224 Bldg.
O. C. Taylor, B-2224 Bldg.
F. P. Boer, B-1225 Bldg.
E. H. Holt, B-2406 Bldg.
L. C. Shepard, B-1219 Bldg.
L. D. Martin, B-1225 Bldg.
D. C. Benefiel, B-1219 Bldg.
W. W. Henslee, B-1225 Bldg.
*H. H. McClure, B-1210 Bldg.
*W. H. Fletcher, B-101 Bldg.
*L. J. Fourrier, A-1201 Bldg.
J. A. VanWestenburg, A-606 Bldg.
*O. N. Hollis, A-1201 Bldg.
*S. F. Edquist, B-101 Bldg.
✓G. E. Rademacher, B-2224 Bldg.
J. D. Laman, B-1226 Bldg.

Canada

*R. C. Young, 726 Bldg.
P. O. Box 1012
Sarnia, Ontario, Canada N7-T7-K7

*J. M. Pasnak
Ft. Saskatchewan
P. O. Box 759
Alberta, Canada TOB-IPO

Louisiana

G. W. Daigre, 2501 Bldg.
H. A. Chagnard, 2501 Bldg.
G. Liu, 2501 Bldg.
*E. P. Edwards, 2601 Bldg.

Midland

F. C. Leavitt, 574 Bldg.
D. R. Beaman, 574 Bldg.
R. O. Kagel, 1603 Bldg.
R. J. Moolenaar, 2020 Bldg.
*D. P. Sheetz, 47 Bldg.
*M. E. Pruitt, 2020 Bldg.
*G. W. Pearson, 2020 Bldg.
*M. E. Kelly, 2020 Bldg.
K. W. Guebert, 474 Bldg.
*D. D. Deline, 834 Bldg.
R. G. Carlson, 2030 Bldg.

Russellville

*G. Miller

ST0463857

The Problem

We are principally concerned with aqueous samples, some with high concentrations of NaCl and/or NaOH. These samples, in general, will contain 10^6 to 10^{10} asbestos fibers/liter (typical concentrations by weight encountered to date are 0.1 - 200 $\mu\text{g/l}$, the fibers being approximately 2 to 9 microns long and 200 to 400 Å in cross section (i. e., 100 to 300 aspect ratio). Although this is the typical case, any particle with an aspect ratio 3 to 1 or larger will constitute a fiber. Representative samples may also be expected to contain additional suspended particulate matter such as: clay minerals (montmorillonite or kaolinite), diatoms, quartz, graphite, hydroxides, and minerals indigenous to the particular sample area. Important chemical and physical characteristics particular to chrysotile are summarized below:

TABLE 1

Physical:

1. Large aspect ratios (100/1 typical).
2. Specific gravity 2.5; density 2.56 g/cc.
3. Loss of crystalline water at 695°C (14 % by wt.).
4. Irreversible change of crystal structure at 840°C .
5. Characteristic I. R. spectrum.
6. Isoelectric point - 10.3.

Chemical:

1. Mg to Si ratio:
Empirical composition: $3\text{MgO} \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ or
 $\text{Mg}_3(\text{OH})_4\text{Si}_4\text{O}_{11} \cdot \text{H}_2\text{O}$, i. e., 43.5 % MgO; 43.5% SiO_2 ; 13% H_2O .
Typical impurities are:¹ Fe, 0-1% ; Al, Ca, Cr (light);
Cu, Na (trace); nickel (medium).
2. pH-- 9 to 10.
3. Soluble in strong acids to 56 % by wt.

¹Sample analyzed by emission spectroscopy on asbestos from Chlor-Alkali department.

The analytical problems associated with asbestos fibers are fourfold: concentration and separation, identification, sizing, and counting. These areas will be dealt with separately with the objective of describing available techniques and evaluating their usefulness.

CONCENTRATION AND SEPARATION

Filtration:

Of the concentration methods, filtration seems to be the most universal. Typically, a millipore®-type membrane made of cellulose esters and having a pore-size between 0.2 - 0.8 μm is employed either in a pressure or vacuum filtration

ST0463858

assembly.^{3, 8, 27, 39 57-60, 67, 68}. These membranes can then be ashed at relatively low temperatures (350°C)^{59, 67}, dissolved, or extracted in order to free the insoluble fraction. The currently used technique employs a EFFA[®] condensation washer wherein the filter is bathed in acetone vapors and condensate until it dissolves. This procedure takes approximately one hour if a 2 mm (dia.) filter is used. An added benefit is that it is possible to wash from the filter soluble material which may interfere with successive analysis. An average filtering time for 1 liter of solution is approximately 10 min/in² of filter. This time will depend on how much clogging is experienced.

Centrifugation:

Centrifugation offers an attractive alternative to filtration in that it is relatively fast and does not involve additional steps to free the filtering agent. It is routinely used as a technique to "spin-down" fibers onto an electron microscope grid⁵⁷ and also as a prefiltering aid to reduce clogging by large particles^{59, 60}.

The use of an ultracentrifuge and density gradient may prove helpful in separating unwanted suspended material from the asbestos fibers. On the other hand, a continuous centrifuge (e. g., Sharpless[®]) might aid in concentration of the particulate matter from a large sample.

Agglomeration and Extraction:

It is well known that hydroxyl groups on the asbestos fibers are subject to attack by chloro- and alkoxy silanes to produce organic derivatives^{15, 42, 47, 52-54, 62}.

It has also been found that agglomeration or graft-polymerization will occur if the silane contains more than one reactive site. If the silane contains bulky organic substituents it may make the asbestos more soluble in organic solvents and thus extraction may be feasible³⁴.

Evaporation:

The disadvantage of this approach is that both soluble and insoluble material will be simultaneously concentrated. If, however, the soluble species can be extracted or perhaps dialyzed, evaporation may still provide a useful concentration method.

Electrokinetic Effect:

Asbestos fibers have been shown to carry a large surface charge (isoelectric point 10.3)^{2, 38} and thus, electrophoresis may be applied in separation and concentration³⁸. Whether or not the majority of fibers can be collected by this technique or if the fibers will be lost when the electrode is withdrawn is not presently known.

ST0463859

IDENTIFICATION METHODS

Methods of low-specificity

Chemical Methods:

Chemical techniques rely on the analysis of both Mg and Si in the bulk sample of suspended matter. The typical procedure is to analyze for both Mg and Si using whichever value is found to be lowest to calculate an upper limit of asbestos present. The particulate matter is solubilized with HF and HClO₄ or by Na₂CO₃ fusion and the Mg and Si are then analyzed by any of a number of wet chemical or instrumental methods. This approach is presently being carried out with atomic absorption spectroscopy at B-2406 of the Texas Central Laboratory (E. H. Holt, private communications).

X-Ray Spectroscopy:

X-ray fluorescence, whether X-ray or electron induced, exhibits a rather low sensitivity for either Mg or Si. It would therefore be doubtful if this technique would be applied successfully.

Atomic Emission Spectroscopy:

Emission spectroscopy does not lend itself easily to quantitative analysis. However, it has been estimated that a lower limit of 20 µg of asbestos can be determined if the sample is fused with Na₂CO₃. Again, it must be recognized that any foreign silicate or magnesium containing compound will interfere.

Radioactive or Chemical Tagging:

It is known that coupling reagents modified to contain a radioactive or fluorescent tag can be affixed to the asbestos fibers. Some of the more likely candidates are the chloro- and alkoxy silanes which contain a grouping which might chelate an easily monitored metal ion. It has been reported that some dyes^{43, 34} can be adsorbed in aqueous solution and also that titrated chrysotile has been synthesized²³. Tagging represents an important concept in the identification of chrysotile. If metal ions, dyes, or other surface active agents can be found to bond specifically to chrysotile this could give a major increment in analytical sensitivity and possibly specificity. Some reports indicate that a degree of specificity has already been observed^{10, 16, 22, 34, 35, 40, 43}.

Infrared:

It has been estimated that chrysotile in the range 20 to 700 µg⁴⁶ can be determined by using the 2.72 µm hydroxyl adsorption. However, this method is non-specific since other hydroxyl containing compounds may interfere. The specificity may

ST0463860

be improved by monitoring the 9-10 μm silicate adsorption.

Even with its drawbacks, I. R. represents a simple, cheap, and relatively fast method by which an upper limit could be obtained and thus may constitute a quick survey technique. A sensitivity of 0.5 μg is readily attained in the absence of interferences.

ESCA:

ESCA can provide a quick semi-quantitative Mg and Si analysis. Its advantage may lie in its ability to look only at the first 50 Å or so of the surface. Thus, if the asbestos can be distributed on the top of a filtering agent, ESCA may be able to do the analysis without removing the filter.

Methods of Moderate to High Selectivity

TGA and DTA:

Chrysotile gives a characteristic endotherm at 695°C associated with its loss of H_2O (13% wt). It also exotherms at temperatures above 800°C which is indicative of a change in crystal structure^{37, 44}.

It has been reported that chrysotile in talc can be detected in the 1.0% range on samples as low as 10 milligrams. Consequently, sample handling would constitute its main liability since the asbestos concentration is expected to be in the microgram/liter range.

THA:

Thermohygrometric analysis²⁸ relies on the detection of evolved water at 695°C using a sensitive hygrometer. If we assume 10 μg of chrysotile is contained in a 10 cc volume of dry gas, the water evolved would be in the parts/1000 range. This could be easily monitored by existing hygrometers. However, it is not known if other compounds will also evolve water at this temperature and thus the specificity of this technique remains in question.

Silicate Extraction:

Silicate minerals can act as sources of trimethylsilyl silicates when reacted with chlorotrimethyl silanes⁶². The particular silicate evolved can be characteristic of the mineral reacted. The trimethylsilyl silicate can be determined by G. C. in some cases. Sensitivity may be a problem, but this technique should be further researched.

Optical Microscopy:

Optical microscopy is considered useful for particles larger than 1 μm in smallest dimension. Since most individual asbestos fibers have been found to have a cross section of less than 0.5 μm , this technique will not be applicable except for looking

ST0463861

at large bundles of fibers. Optical microscopy is widely used for analysis of asbestos in air samples^{9, 40, 55}.

Transmission Electron Microscopy:

TEM combined with selected area electron diffraction (SAED) and energy dispersive X-ray analysis (EDX) can identify, count, and size individual asbestos fibers. Its liability lies in involved sample preparation, small field of view, tediousness, and considerable capital investment. The usual technique is to filter the fibers onto a filtering membrane. The membrane is then ashed or dissolved and the residue dispersed onto a microscope grid (see filtering techniques). This technique is presently the standard method for chrysotile analysis. It can be successfully used to detect chrysotile in the ng range^{3, 27, 33, 51, 57-61}.

Scanning Electron Microscopy:

As far as sample preparation, SEM offers an advantage over TEM in that the filter does not have to be removed. Aside from this advantage, the inherently lower resolution and lesser degree of contrast should make SEM inferior to TEM as a method for asbestos analysis and fiber counting.

However, recent literature from the Kevex® Corp. indicates that X-ray spectroscopy, in conjunction with scanning electron microscopy (SEM), can be used to analyze individual asbestos fibers.

X-Ray Diffraction:

X-ray analysis is probably the most specific technique. It is not easily quantified except by elaborate standardization, and under normal circumstances is not very sensitive. Sensitivity is in the range 10 to 100 mg²¹, but claims have been made of analysis in the 50 to 100 µg range²⁴. The standard lines used for this analysis are the 7.36 Å and 3.66 Å lines.

COUNTING AND SIZING

The only direct method of counting fibers seems to be electron microscopy. However, if the asbestos fibers are found to fall within a certain size range, then bulk measurements of asbestos in a sample can be extrapolated to fibers present. Indirect measurements of the number of particles may be realized by applying one of the following concepts:

1. Light scattering: This technique offers a possible avenue for counting and sizing. The major problems arise from interference by other suspended particles, absorption of light by colored solutions, and in not knowing how these fibers will scatter. It is also unknown at present if light scattering can detect asbestos in the ppm or ppb concentration range.

ST0463862

2. Centrifugation: The Joyce-Loebl® disc centrifuge will allow for sedimentation and separation of particles based mainly on specific gravity differences. Its use of light scattering as a detection technique will also depend on whether or not these fibers will scatter in the visible light region.

Summary

At present, TEM stands as the one technique which fulfills all analytical needs (i. e., identification, counting, and sizing). However, a complimentary, rapid survey analysis which can give an order of magnitude asbestos concentration and could be implemented into a production facility is needed. The techniques discussed here, especially atomic absorption, I. R., light-scattering, adsorption of dyes and tracers, and other chemical methods are being further evaluated as rapid analytical procedures and recommendations will be forthcoming.

Bibliography
1967 - Present (Sept., 1974)

This bibliography has been compiled from the following sources:

- A. Chemical Abstracts -- 1967 to September, 1974.
- B. Dow Computer Search which lists: Engineering Index
NTIS
Chemical Abstracts (1972-Present)
- C. Dow CRI

-
1. 80-2343q¹ Fed. Registr. 28 Sept. 1973, 27076-81.
Gives specifications and limits for asbestos in air.
 2. 80-64137j J. Appl. Chem. and Biotechnol, 23 (9), 675 (1973).
Talks about different surface charge concentrations of asbestos minerals.
 3. 80-51909n Int. Symp. Indent. Meas. Environ. Pollut., 1971, 154-7.
Asbestos in air is detected by low temp. ashing, ultrasonic breakdown, and TEM gives levels found.
 4. 80-137024g Fed. Registr. 26 Feb., 1971, 38(39) 7526-33.
Limits and regulations.
 5. 80-99654c Report 1973 UCRL-51422 5-7.
Radio induced thermoluminescence of asbestos can be used as detection technique but there are interferences from quartz, etc.
 6. 80-90702j Thermochemica Acta., 8 (1-2), 197 (1974).
DTA was used to detect chrysotile in talc down to 1% by wt.
 7. 81- J. Occup. Med. 15 (2), 92 (1973).
Review of toxicological effects.
 8. 81-16279f U.S. Nat. Tech. Inform. Serv., PB Reb. 1973 No. 226471/1GA.
Avail. NTIS from Gov. Rep. Announce 1974, 74 (6) 81.
Using SEM with microprobe the gov. has developed a method to scan air samples.

¹Chemical Abstract No.

ST0463864

9. 78-9295p Proc. Elect. Microsc. Soc. Amer., 30, 356 (1972).
Atlas including diffraction patterns and description of fibers using light and electron microscopy.
10. 79-68556x Zh. Prikl. Spettrosk., 18 (5), 914 (1973) Russ.
Showed all asbestos luminesced when excited by U. V. in 370-620 nm. Samples displayed thermoluminescence when excited by X-rays.
11. 79-81607j Ustar. Jad. Vyzk., Cesk. Akad. Ved., 1972, No. 2851-F-Ch 86 pp. (Eng.).
X-ray spectra of asbestos.
12. 78-33508k Proc., Elect. Microsc. Soc. Amer., 30, 546 (1972).
SAED patterns for various minerals including chrysotile.
13. 78-143447 Staub.-Reinhalt. Luft., 33 (2), 66-70 (1973) Ger.
Quant. detection of asbestos by optical, chemical X-ray, and I. R. techniques.
14. 78-150831w TNO Nieuws., 27 (11), 661 (1972) Eng.
Discusses pattern of filtration, phase contrast microscopy, TEM, I. R., XRD, Elect. Diff.
15. 77-20074v Bull. Soc. Chim. Fr., 1, 54 (1972) Fr.
Reaction of chrysotile with dichlorosilanes for grafting.
16. 79-58074z Patent - Pol 67, 335, 20 Feb. 1973.
Asbestos impregnated with rare earths, etc., for ion exchange membranes.
17. 70-108184x Sb. Nar. Mus. Praze, 24b (1), 61 (1968) (Eng.).
Mineral identification of chrysotile by chemical, optical, DTA, XRD.
18. 74-102752s Proc. Int. Conf. 3rd 1969 (pub. 1970), 52 (Eng.).
Neutron-activation technique to investigate biological effects of asbestos.
19. 75-91036d Atmos. Environ., 5 (7) 565 (1971).
I. R. for airborne asbestos.
20. 80-148689d Lyon Pharm., 1973, 24 (5) 627 (1973) Fr.
Industrial micropollutants.

ST0463865

21. Analyst (London), 94 (1124) 985 (1969) (Eng.).
Quant. XRD for chrysotile.
22. 70-132503z Vzainodeisfuse Vodora. Policle. Disp. Sist., 83 (1970) Russ.
Coagulation and bonding in asbestos suspensions in the
presence of electrolyte K-4.
23. 70-45539x Environ. Res., 4 (2), 86 (1971).
Synthesis of ³H-labeled chrysotile.
24. Analytical Chem., 44 (11), 1872 (1972).
by XRD 50-100 µg of chrysotile can be detected.
25. 70-123172x Zem.-Kalk-Gips, 23 (8) 390 (1970) (Ger.).
TGA of chrysotile.
26. 69-22881q Acta. Cryst., 24 (3) 374 (1968).
Measurement of position and 1/2 height width of some
reflections of chrysotile.
27. 69-1556664 Dokl. Akad. Nauk. SSSR, 200 (4) 953 (1971) (Russ.).
TEM of natural and synthetic chrysotile.
28. 69-142677y Clay Miner., 9 (1) 19 (1971).
Thermohygrometric analysis (water evolved) of clay minerals.
29. 69-560736 U. S. Geol. Surv. Prof. Papers, No. 384-B, 93, 1967.
Different solution methods for discriminating asbestos.
30. 69-305975 Geochim. Cosmochim. Acta., 32 (5) 485 (1968).
Solubility of chrysotile.
31. 69-24053u Hokkaido. Daigaku. Kogakuku Kenkyu Hohoku, 1967, (45), 81
(1967) Russ.
Synthesis chrysotile with fluoride substituted for OH⁻.
32. 70-108823e IZV. Akad. Nauk. SSSR, Neorg. Mater., 5 (1) 143 (1967) Russ.
Reactions of chrysotile with various chlorosilanes.
33. 67-7044h Kristallografiya, 12 (3) 430 (1967) Russ.
Study of wall thickness of fibers of chrysotile.

ST0463866

34. 67-100166 Patent (US) 3,346,111 Oct., 1967.
Asbestos coated with fluorescent dye is made selectively fluorescent.
35. 66-21861j Patent (Ger.) 1,226,505 Oct. 13, 1966.
Surfactants can be used to precip. asbestos suspensions with organic solvents.
36. 68-80358m Vop. Min. Osad. Obrazov., 7, 48 (1966) Russ.
I. R. spectra of chrysotile.
37. 67-74039z Plast. Inst. Trans. J., 35 (117) 525 (1967).
38. 69-29885c Patent (Brit.) 1,115,221.
Anionic asbestos fibers are drawn to anode for continuous stripping.
39. 74-6242e U.K. At. Energy Auth., At. Weapons Res. Estab., Rep. 1970
AWRE 028/70 Avail. HMSO 95.
Discusses membrane filters, impingers, cascade impacters, horizontal elutriators.
40. 72-84369z Microscope, 18 (1), 1 (1970).
Dispersion staining discussed.
41. 73-59034b Atmos. Environ., 4 (2) 125 (1970).
Internal reflection used to determine chrysotile.
42. 66-115792q Patent (USSR) 185,858.
Organic derivatives of silicates using colloidal nickel catalyst.
43. 66-67812x Tr. Inst. Geol. Nauk., Akad. Nauk. Kaz. S.S.R., 16,
201 (1966) Russ.
Applying organic dyes to asbestos.
44. 75-54544x Kristallografiya, 16 (3) 544 (1971) Russ.
TGA and DTA shows endotherm 695°C releasing 2 mol of H₂O and exotherm 840°C assoc. with transition to MgSiO₂.
45. 72-6029 Arbeitsschutz (Cologne), 7, 161 (1969) Ger.
I. R. spectra of chrysotile.

ST0463867

46. 74-102730h Atmos. Environ., 4 (16) 667 (1970).
Uses the 2.72 μm absorption to detect 20 μg of chrysotile, some interference is also experienced.
47. 72-8812y Khim. Prakt. Primen. Kremniorg. Soedin., Tr. Sovesch. 186 (1966).
Ethoxy silanes react with chrysotile in the presence of Ni catalyst.
48. 72-112662k J. Appl. Chem., 20 (3) 76 (1970).
I.R. study of silanes coupled to chrysotile.
49. 71-93424v Clays and Clay Minerals, 14, 367 (1964) (Pub. 1966).
Neutron inelastic scattering of chrysotile shows peaks at 620-650 cm^{-1} and 460-510 cm^{-1} .
50. 73-17270x Amer. Mineral, 55 (5-6) 1025 (1970).
Chemical differences of asbestoses.
51. 68-72576 Acta. Cryst., 23 (5) 704 (1967).
High resolution TEM.
52. 70-87028q Patent (USSR) 228, 947.
Organic derivatives of silicates.
53. 68-30271k U.S. Clearinghouse Fed. Sci. Tech. Inform. AD 649281, 1967.
Chrysotile reacts with HCl and Me_3SiCl to form curled ribbons.
54. 69-7908k Bull. Soc. Chim. Fr., 2, 483 (1968).
In acidic solution Mg was removed from chrysotile. Hexamethyldisiloxane was added to give chrysotile polymer.
55. Arch. Environ. Health, 20, 571 (1970).
Describes asbestos fibers under TEM.
56. Toxic Materials News, Aug. 15, 1974.
How EPA plans to move on asbestos pollution.
57. Science, 185 (4154), 853 (1974).
Chrysotile by TEM.
58. Science, 177, 171 (1972).
Asbestos in drugs. TEM analysis described.

ST0463868

59. Nature, 219, 93 (1968).
Asbestos in beer. TEM analysis described.
60. Nature, 233, 332 (1971).
Asbestos in beverages. TEM analysis described.
61. Water Pollut. Control, 111, 33 (1973).
Search for asbestos in drinking water; analytical techniques described.
62. Inorganic Chem., 3, 574 (1964).
Organic derivatives of silicates as means for identification.
63. Science, 173, 1141 (1971).
Talc treated rice and Japanese stomach cancer.
64. American Lab., 13, April, 1974.
Optical microscopic techniques.
65. TDI - TC-347 Dow Report.
Dissolving of asbestos.
66. Analytical Chem., 45 (4) 609 (1973).
TEM analysis.
67. Amer. Industrial Hy. Assoc. J., 31, 587 (1970).
Techniques for the detection, identification and analysis of fibers.
68. Proc. 67th meeting of APCA, June (1974), Denver, Colo.
Note on filtering samples from air using two nucleopore filters.
69. Inorg. Chem., 6 (9), 1693 (1967).
Reaction of chrysotile with HCl and trimethyl chlorosilane to form a fibrous polymer.

ST0463869