FILE NAME: Asbestos in Plastics (AIP)

DATE: 2005 Oct

DOC#: AIP009

DOCUMENT DESCRIPTION: Journal Article - Occupational Exposure to Airborne Asbestos from Phenolic Molding Material - Bakelite - During Sanding, Drilling, and Related Activities

Journal of Occupational and Environmental Hygiene, 2: 497–507
ISSN: 1545-9624 print / 1545-9632 online

DOI: 10.1080/15459620500274237

Occupational Exposure to Airborne Asbestos from Phenolic Molding Material (Bakelite) During Sanding, Drilling, and Related Activities

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In this study, a historical phenolic (Bakelite) molding material, BMMA-5353, was tested to determine the airborne concentrations of asbestos fibers released during four different activities (sawing, sanding, drilling, and cleanup of dust generated from these activities). Each activity was performed for 30 min, often in triplicate. The primary objective for testing BMMA-5353 was to quantitatively determine the airborne concentration of asbestos fibers, if any, in the breathing zone of workers. Uses of this product typically did not include sawing or sanding, but it may have been drilled occasionally. For this reason, only small quantities were sawed, sanded, and drilled in this simulation study. Personal (n = 40), area (n = 80), and background/clearance (n = 88) air samples were collected during each activity and analyzed for total fiber concentrations using phase contrast microscopy (PCM) and, for asbestos fiber counts, transmission electron microscopy (TEM). The raw PCM-total fiber concentrations were adjusted based on TEM analyses that reported the fraction of asbestos fibers, to derive a PCM-asbestos concentration that would enable calculation of an 8-hour time-weighted average (TWA). The estimated 8-hour TWAs ranged from 0.006 to 0.08 fibers per cubic centimeter using a variety of worker exposure scenarios. Therefore, assuming an exposure scenario in which a worker uses power tools to cut and sand products molded from BMMA-5353 and similar products in the manner evaluated in this study, airborne asbestos concentrations should not exceed current or historical occupational exposure limits.

Keywords asbestos, Bakelite, industrial hygiene, occupational exposure, phenolic molding materials

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In the early 1900s, Belgian chemist Leo Baekland discovered the method for combining phenol and formaldehyde to form the first synthetic thermosetting plastic, which he named Bakelite.[1–3] The plastic resin compound was quite versatile and numerous uses were soon found for it, including production of automotive and electrical parts, abrasive wheels/sandpaper, appliances, and foundry molds. Phenolic resins have good chemical and thermal resistance, dielectric strength, and dimensional stability.[1,4] Products made with these resins are inherently low in flammability, are creep resistant, and have low moisture absorption. Due to these characteristics, phenolic resins have been in commercial use longer than any other synthetic polymer with the exception of cellulose nitrate.[1]

Bakelite and other thermosetting resins were valued especially for their thermal and electrical insulation properties and were used primarily in the electrical and electronics industries, with other uses in appliances and the rubber industry.[1,4,5] Fillers such as chrysotile asbestos were added to the plastic to improve its properties.[6] Other fillers included wood flour, walnut shells, shredded paper, mica, and fibrous glass. The abundant supply and low cost of asbestos, combined with its fireproof nature, chemical inertness, ease of mixing, and reinforcement properties, led to its use in many applications. Since the 1970s and 1980s, however, concerns about the health hazards posed by asbestos-containing products have led to a gradual decline in use of these fillers. However, due to the historical popularity of Bakelite and other thermosetting resins, sometimes these products are still present in older buildings in various industries. There is a lack of information in the published literature regarding exposure levels associated with phenolic molding compounds; thus, this exposure simulation was undertaken to quantify these exposures and evaluate the airborne asbestos health hazard.

When evaluating the possible health hazard associated with asbestos-containing materials (ACM), two categories of ACM are usually cited: (1) those containing free fibers or that are friable, and (2) those containing encapsulated fibers or are not friable. The hazard potential for these two categories has been known for decades,[7] and they were included in the regulations of the Occupational Safety and Health Administration (OSHA) at their inception.[8] Exposure to asbestos fibers occurs when workers handle and process raw asbestos fibers, which can become airborne in their dry form, or when someone works with friable products (e.g., insulation). In contrast, ACMs with asbestos fibers that are encapsulated or bonded with other materials, such as resins, cement, and other bonding agents, limit the potential for airborne release. The term "encapsulated asbestos" applies to fibers that are coated with a material or wetted with a binder, resin, or other medium, thereby containing the asbestos fibers within a solid matrix and limiting their potential to become airborne (e.g., asbestos in automotive brake pads, vinyl composite floor tiles, floor mastics, roofing tars). These fibers are considered to pose a negligible health hazard because of the inability of appreciable concentrations to become airborne and because the presence of the encapsulating medium inside and outside of the fiber may significantly reduce (or eliminate) its adverse effects.[9,10] In short, due to the encapsulation of asbestos fibers in a solid matrix, which serves to coat or saturate the fibers with a bonding agent, only relatively low airborne concentrations of asbestos fibers are expected to be present during manipulation of most encapsulated products. The low potential for release of fibers from these kinds of products is acknowledged in the federal regulations, wherein OSHA, in 1972, did not require asbestos caution labeling requirements for fibers that have been "modified by a bonding agent, coating, binder or other material."[9] This labeling requirement still exists today, as evidenced by the lack of warnings on most driveway sealants and roof coatings that contain asbestos.

In the present study, we evaluated the potential for release of asbestos fibers from mechanical manipulation of BMMA-5353, a phenolic molding compound that was manufactured by the Union Carbide Company from the late 1960s through 1974. Phenolic molding compounds were commonly used to manufacture parts for automotive purposes and in appliances. These molded products were almost always manufactured for specific uses (i.e., molded to the specific shape needed). The primary objective for testing this phenolic molding compound was to quantitatively determine the airborne concentration of asbestos fibers, if any, that may be released to air during the cutting, sanding, and drilling that may have been associated with some uses in the field. These airborne concentrations were then compared to current and historical workplace occupational exposure limits (OELs).

MATERIALS AND METHODS

For this study, BMMA-5353 was manufactured in a pilot-plant setting during February and March 2003 based on historical formulation information. The manufactured material is composed of a Novolac resin (a phenolic two-step resin) and contains 31% chrysotile asbestos (Jeffrey Mine 7RF-3) by weight. BMMA-5353 is molded to provide a rigid product with a hard, smooth surface with excellent dimensional stability and heat resistance, fast cure, and low mold shrinkage. When manufacturing this product, standard specifications for phenolic molding compounds were followed (American Society for Testing and Materials [ASTM] D700-88)[11] for a Type 13 material (medium-specific-gravity compounds containing mineral and other organic fillers formulated for heat-resistant applications). The characteristic properties of the formulated BMMA-353 included specific gravity of 1.66 (ASTM D700-88 calls for specific gravity of 1.68) and notched impact of 0.3 foot pounds per inch. We did not measure impact, flexural, or deflection strength of BMMA-5353, as described in ASTM D700-88, because insufficient material was formulated to cut out or machine shapes made from BMMA-5353. In addition, the BMMA-5353 product specification does not provide guidelines for the molded material, stating only that the granules used should have spiral flow and plasticity, certain apparent density and sieve size distribution, and specific appearance.

The plasticity of the product was determined by its ability to fill a specified mold, and the granule sieve size distribution was within specified size limits to allow for full melting and formation of a uniform product. Apparent density is related to the bulkiness of the material before molding and therefore does not affect performance; however, the final appearance of the product was within specifications, so it was deemed that the density was within limits.

For this study, BMMA-5353 was molded into test panels that were 10.2 cm long, 15.2 cm wide, and 0.6 cm high (approximate total surface area of 342 cm^2 each) to allow for manipulations of the compound to be conducted. These manipulations included sawing, sanding, and drilling using power tools. Following each procedure, cleanup of dust generated from these activities was conducted as a separate test.

Testing Facility

All tests of BMMA-5353 were carried out in an indoor test chamber that was 4.9 m long, 4.9 m wide, 2.4 m high (58 m^3) in Monroeville, Pa. (Figure 1). A table was centered in the room as a work surface. A single worker performed each test. A high-efficiency particulate air (HEPA) filter operating at approximately 4.2 to 4.6 m^3/min was used, creating an air exchange rate in the testing room of approximately four to five exchanges per hour.

Testing Procedures

BMMA-5353 was tested to evaluate the potential release of asbestos fibers from the following activities: sawing, sanding, drilling, and cleanup of dust generated from these activities. For purposes of this study, the activities represent aggressive handling of the product, thus simulating a worst-case scenario. For each activity, high-speed, freestanding, industrial-grade equipment (i.e., power tools) was used to aggressively machine the BMMA-5353 panels.

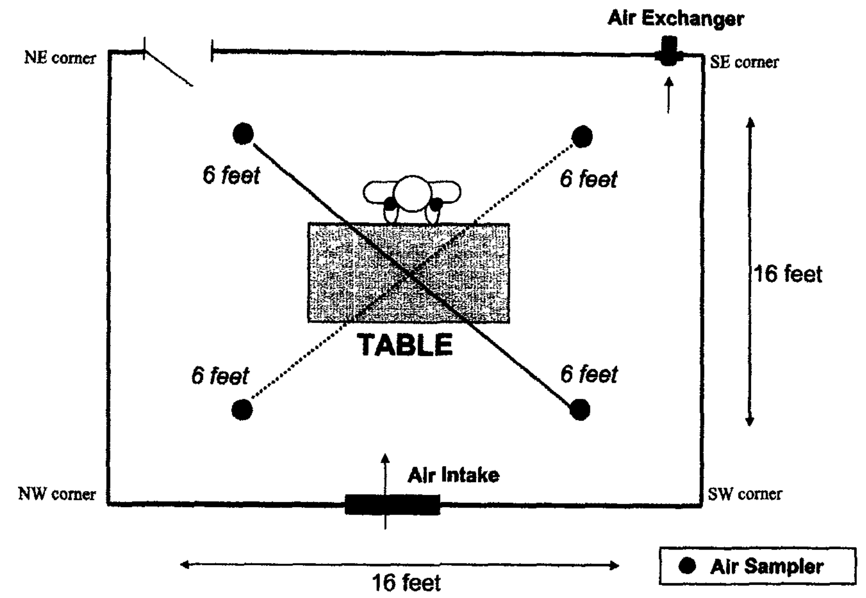

FIGURE 1. Schematic of testing facility

Testing Protocol

Four different activities were examined in the testing program: (1) band sawing of test panels, (2) belt sanding of panels, (3) press drilling of panels, and (4) sweep cleanup of the work area. The duration of the testing period was set based on the available quantity of the remanufactured testing material for completing four replicate tests.

(1) *Band Sawing Test.* The sawing test used a Delta BS100 band saw (1/3 hp, 1725 rpm; Delta Woodworking Machinery, Jackson, Tenn.) to cut the test panels into strips. No local exhaust ventilation was used during this test. The saw blade had a width of 0.4 cm and six teeth to the inch. During each 30-min replicate of the sawing test, a BMMA-5353 test panel was cut using the band saw, which was placed on the table centered in the testing room. Seven cuts were made on the test panel, creating eight strips, each 10.1 cm long, 1.9 cm wide, and 0.6 cm deep (for a total of 71 linear centimeters per test). Four replicates of the sawing test were performed. The third replicate was aborted due to band saw failure during the test.

(2) *Belt Sanding Test.* The sanding test used a Craftsman Model #351 belt sander (1.5 hp, 3450 rpm; Sears, Hoffman Estates, Ill.) to sand the edges of the test strips that remained from the sawing test. The sandpaper used was 240 grit for 30 min per test. Again, no local exhaust ventilation was used during this test. During each 30-min replicate of the sanding test, a worker beveled the edges of the test strips using a bench-mounted belt sander centered in the testing room. Approximately 0.75 linear meters of material were beveled. Four replicates were performed.

(3) *Drilling Press Test.* The drilling test used a Craftsman Model #137 drill press (2340 rpm; Sears) to drill holes into the test strips. No local exhaust ventilation was used during this test. During each 30-min replicate of the drilling test, 0.32-cm holes were drilled into the test strips, for a total of 32 holes. Four replicates were performed, for a total of 128 holes drilled.

(4) *Sweep Cleanup Tests.* The sweep cleanup tests consisted of cleaning up the material generated during each of the prior three activities. During the sweep cleanup test for sawing, a small, hand-held brush was used to brush any surface debris from the band saw. A hand-held broom was then used to brush debris from the table surface and floor. For the sanding and drilling sweep cleanup tests, a hand-held broom was used. All debris was swept into a dustpan and disposed of in a disposal container. A total of nine replicates (each 30 min in duration) of the cleanup tests were performed.

Air Sampling

During each 30-min replicate of the four tests, two personal air samples were collected from the worker's breathing zone by placing the sampling devices over the right and left shoulders. The samples were collected on 0.8-μm (pore size), 25 mm diameter mixed cellulose ester (MCE) filters (Zefon International, St. Petersburg, Fla.). Personal air samples were collected at a flow rate of approximately 1.7 L/min depending on the test type. Four area air samples were also collected during each replicate at a distance of approximately 1.8 m from the center of the work surface and at a height of 1.5 m.

Area samples were collected on 0.45 μm (pore size), 25 mm diameter MCE filters. These samples were collected at a flow rate of approximately 2 to 5 L/min, depending on the test type. Specific air sampling rates for each test and sample type (area and personal) were determined from a particulate loading study that was conducted prior to this study. The goal of this study was to determine the appropriate flow rate to achieve the lowest limit of detection possible without collecting so much dust that the filter was overloaded, which would prevent quantification of asbestos fibers.

Four background or four clearance air samples were collected in the testing room prior to and following each test. These samples were collected as area samples using the four perimeter pumps located in the testing room. Samples were collected on 0.8 μm pore size, 25 mm diameter MCE filters. The background samples were collected prior to each of the sawing, sanding, or drilling tests to provide information on ambient concentrations of total and asbestos fibers in the air of the test room prior to the sweep cleanup tests. Background samples were collected for at least 1 hour at a flow rate of 10 L/min. Clearance samples were also collected following each sweep cleanup test. These samples were generally collected for 2 hours at a flow rate of 10 L/min.

All personal, area, and background/clearance samples collected during testing were analyzed by phase contrast microscopy (PCM) to determine total fiber concentrations (asbestos and nonasbestos) using NIOSH Method 7400.(12) Samples were also analyzed by transmission electron microscopy (TEM) using NIOSH Method 7402(13) to determine the fraction of airborne fibers that are asbestos. Individual filters were obtained for the PCM and TEM analyses, which were sampled separately. As prescribed in NIOSH Methods 7400 and 7402, only fibers that were 5 μm or greater in length, with an aspect ratio of at least 3:1, were counted. Standard quality assurance and quality control procedures were followed at all times.

Calculation of PCM-Asbestos Concentrations

In accordance with NIOSH Method 7402, the total fiber concentration obtained by PCM was converted to a PCM-asbestos concentration using the asbestos-to-total-fiber ratio by TEM. The PCM-asbestos concentration represents the fraction of PCM total fibers estimated to be asbestos fibers. The PCM-asbestos concentrations were then used to calculate an 8-hour time-weighted average (TWA) in an attempt to estimate the airborne concentration during a typical workday. Calculations of 8-hour TWAs allowed for comparisons to the OSHA permissible exposure level (PEL).

Calculation of Estimated 8-Hour Time-Weighted Averages

Typically, personal air samples are the best indicator of worker exposure. Eight-hour TWAs were calculated to (1) estimate potential exposure of workers conducting these activities for 0.5-hour, 1-hour, or 2-hour durations during the 8-hour workday, and (2) allow for direct comparison to current and historical occupational limits or guidelines. These 8-hour TWAs represent a worst-case analysis, because the 8-hour TWA calculations include large amounts of machining, and because workers would not typically be engaged in aggressively machining BMMA-5353 products.

The estimated 8-hour TWA was calculated using the following equation:

$$\sum_{i=1}^{n} \frac{(c_i)(t_i)}{8} \tag{1}$$

where

n = the total number of activities evaluated in a particular scenario

c_i = PCM-asbestos concentration measured during activity i (in fibers/mL, where activities include sawing, sanding, drilling, and cleanup of dust generated from these activities)

t_i = duration of activity i performed by a worker (in hours).

When calculating the 8-hour TWA, the sum of all t_i must equal 8 hours. Given the fact that products are generally molded to fit and require little or no lengthy manipulation, it was assumed that a worker would perform any of the activities (sawing, sanding, drilling, or sweep cleanup) for no more than 0.5, 1, or 2 hours within an 8-hour day.

RESULTS

The weight of the test panels was measured before and after manipulation to determine the amount of material that was removed during each activity (Table I). Based on the machining manipulations conducted in this test, between 1.4% and 3.4% of the material was removed (some of which

TABLE I. Weight Changes for BMMA-5353 Test Material Pre- and Post-Manipulation

Test	Replicate	Weight (g) Start	Weight (g) End	Difference (g)	Difference Percent of Original Weight
Band sawing[A]	a	160.1	154.7	5.4	3.4
	b	164.6	159.4	5.2	3.2
	c	157.6	152.2	5.4	3.4
Belt sanding	a	154.7	152.5	2.2	1.4
	b	159.4	156.1	3.3	2.1
	c	166.3	160.7	5.6	3.4
	d	152.2	148.1	4.1	2.7
Press drilling	a	152.5	150.4	2.1	1.4
	b	156.1	153.8	2.3	1.5
	c	160.7	156.0	4.7	2.9
	d	148.1	145.4	2.7	1.8

[A]Only three replicates were conducted of the sawing test because one test was aborted due to band saw failure.

became airborne). Although this is a relatively limited amount of material on a weight loss basis, the manipulations conducted were considered to be aggressive. Exposure levels obtained from the testing are thought to be representative of a worst-case scenario because products were generally molded to fit, precluding the need for cutting and machining. Thus, if cutting or machining occurred, it was a rare event.

Fiber release results are reported as raw values (as opposed to 8-hour TWAs), with average values calculated using the full detection limit for samples reported as below the detection limit. Average values presented in the tables were calculated using both the full detection limit and one-half of the detection limit for samples reported as below the detection limit. The average results discussed in the text use the full detection limit because this measure is more conservative, and use of the full detection limit did not markedly change the averages.

Total Fibers

The detection limits for total airborne fibers using the PCM method ranged from 0.041 to 0.053 fibers per cubic centimeter (f/cc) for the personal samples, from 0.016 to 0.045 f/cc for the area samples, and from 0.002 to 0.009 f/cc for the background/clearance samples. This range in detection limits is due to variation in the air volumes sampled during the different tests. Because the area and background/clearance samples were collected at a higher flow rate than the personal samples, a larger volume of air was sampled and a lower detection limit could be achieved. Total fibers (which are composed of asbestos fibers, other noncountable asbestos fibers, and other nonasbestos fibers such as cotton fibers from the worker's clothing) were present at detectable concentrations in 22 of the 40 personal samples (Table II), in 48 of the 80 area samples (Table III), and in 31 of the 88 background/clearance samples (Table III).

The results for the personal and area air samples collected during the sawing, sanding, drilling, and sweep cleaning tests are summarized in Tables II and III. The average total airborne fiber concentrations for the personal and area air samples collected during the sawing tests were 0.13 f/cc (<0.05–0.23) and 0.10 f/cc (<0.04–0.35), respectively. For the sanding test, the average total fiber concentrations for the personal and area air samples were both 0.06 f/cc (personal, <0.05–0.09 f/cc; area, <0.05–0.09 f/cc). The average total airborne fiber concentrations for the personal and area air samples collected during the drilling tests were 0.05 f/cc (<0.04–0.07 f/cc) and 0.02 f/cc (<0.02–0.02 f/cc), respectively. Finally, the average total fiber concentrations for the personal and area air samples collected during the sweep cleanup tests were 0.07 f/cc (<0.05–0.18 f/cc) and 0.03 f/cc (<0.02–0.08 f/cc), respectively.

Asbestos Fibers

Asbestos fibers were detected in 25 of the 40 personal samples (Table II), in 52 of the 80 area samples (Table III), and in 18 of the 88 background/clearance samples (Table III). The results for the personal and area air samples collected during the sawing, sanding, drilling, and sweep cleaning tests are presented in Tables II and III. Using TEM analyses, asbestos fibers were detected in all 6 of the personal samples and in all 12 of the area samples collected during the sawing test. They were also detected in all 8 of the personal samples and in all 16 of the area samples collected during the sanding test. During the drilling test, measurable concentrations were noted in only 1 of the 8 personal samples and in only 2 of the 16 area samples collected during the test. Finally, during the sweep cleanup test, asbestos was detected in 10 of the 18 personal samples and in 22 of the 36 area samples.

The PCM-asbestos concentrations ranged from <0.01 to 0.21 f/cc for the personal samples (Table II), from <0.0003 to 0.32 f/cc for the area samples (Table III), and from <0.0004 to 0.005 f/cc for the background/clearance samples (Table III). For the personal samples, the average PCM-asbestos concentrations for the sawing, sanding, drilling, and sweep cleanup tests were 0.11 f/cc (<0.04–0.21 f/cc), 0.04 f/cc (<0.02–0.05 f/cc), <0.01 f/cc, and 0.02 f/cc (<0.01–0.08 f/cc), respectively (Table II). For the area samples, the average PCM-asbestos concentrations for the sawing, sanding, drilling, and sweep cleanup tests were 0.08 f/cc (<0.03–0.32 f/cc), 0.04 f/cc (<0.03–0.08 f/cc), 0.01 f/cc (<0.003–0.2 f/cc), and 0.01 f/cc (<0.003–0.03 f/cc), respectively (Table III). The average PCM-asbestos concentrations for the background/clearance samples associated with the sawing, sanding, drilling, and sweep cleanup tests were 0.001, <0.001, <0.001, and 0.002 f/cc, respectively (Table III).

Background and Clearance Samples

For PCM analyses, total fibers were detected in 31 of the 88 background and clearance samples, with concentrations ranging from <0.002 to 0.01 f/cc (Table III). Most samples were detected at concentrations <0.001 f/cc. The average total fiber concentrations for the background and clearance air samples collected during the sawing, sanding, drilling, and sweep cleanup tests were 0.004 f/cc, 0.002 f/cc, 0.003 f/cc, and 0.005 f/cc, respectively. Using TEM analyses, asbestos fibers were detected in 8 of the 88 background and clearance samples but were detected at very low concentrations (usually <0.001 f/cc). The average PCM-asbestos concentrations for the background and clearance air samples collected during the sawing, sanding, drilling, and sweep cleanup tests were 0.001 f/cc, <0.001 f/cc, <0.001 f/cc, and 0.002 f/cc, respectively.

Estimated 8-Hour TWA Concentrations

Using the PCM-asbestos concentration from the personal air samples, an upper-bound 8-hour TWA air concentration was calculated based on hypothetical exposure scenarios. For calculation purposes, it was assumed that a worker might perform any of the activities for 0.5, 1, or 2 hours. The estimated 8-hour TWAs were derived using maximum and average PCM-asbestos concentrations for personal and background samples for each test activity.

Assuming a worst-case scenario where a worker conducts all the activities evaluated in this study for 2 hours each,

TABLE II. Summary of Results of Personal Air Samples

Test	Replicate	PCM Total Fiber Concentration (f/mL)	TEM Data: Asbestos Fibers	TEM Data: Nonasbestos Fibers	TEM Data: Ratio[A] (f/F)	PCM-Asbestos Concentration[B] (f/mL)
Band sawing[C]	a	0.06	18.5	2	0.90	0.05
	a	<0.05	13	2	0.87	<0.04
	b	0.11	21	5	0.81	0.09
	b	0.12	11.5	1	0.92	0.11
	c	0.20	28.5	3.5	0.89	0.18
	c	0.23	28	2	0.93	0.21
	Maximum	0.23				0.21
	Average[D]	0.14				0.13
	Average[E]	0.12				0.11
Belt sanding	a	0.09	5	8	0.39	0.03
	a	0.05	27	11	0.71	0.03
	b	0.05	8	3	0.73	0.03
	b	<0.05	13	4	0.77	<0.03
	c	0.07	15	3	0.83	0.05
	c	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	d	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	d	[illegible]	[illegible]	[illegible]	0.92	<0.04
	Maximum	[illegible]				0.05
	Average[D]	[illegible]				0.04
	Average[E]	[illegible]				0.03
Operating drill press	a	<0.04	0	2.5	0	<0.01
	a	<0.04	[illegible]	0.5	0	<0.01
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	<0.01
	[illegible]	<0.05	[illegible]	[illegible]	0	<0.01
	b	<0.05	[illegible]	1	[illegible]	[illegible]
	b	<0.05	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	1	[illegible]	<0.01
	b	<0.05	0	0	0	[illegible]
	c	<0.04	0	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	1	0	<0.01
	c	<0.04	0	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	<0.01
	c	<0.04	0	4	0	<0.01
	d	0.07	0	2	0	<0.01
	d	<0.04	1	3	0.25	<0.01
	Maximum	0.07				0.01
	Average[D]	0.05				<0.01
	Average[E]	0.03				<0.01
Sweep cleanup						
Sawing	a	0.10	1	5	0.17	0.02
Sawing	a	0.06	4	3.5	0.53	0.03
Sawing	b	<0.05	1	1	0.50	<0.02
Sawing	b	<0.05	0	1	0.00	<0.01
Sanding	a	<0.05	1	0	1.00	<0.05
Sanding	a	<0.05	4	2	0.67	<0.03
Sanding	b	<0.04	0	1	0.00	<0.01
Sanding	b	0.04	1	3	0.25	0.01
Sanding	c	0.18	3	4	0.43	0.08
Sanding	c	0.11	0	2	0.00	<0.01
Drilling	a	0.05	0	4	0.00	<0.01
Drilling	a	0.06	0	6	0.00	<0.01
Drilling	b	0.07	0	6	0.00	<0.01
Drilling	b	<0.05	2	5	0.29	<0.01
Drilling	c	0.07	0.5	1	0.33	0.02
Drilling	c	0.09	2	3	0.40	0.04
Drilling	d	0.06	0	1.5	0.00	<0.01
Drilling	d	<0.05	0	0	0.00	<0.01
	Maximum	0.18				0.08
	Average[D]	0.07				0.02
	Average[E]	0.06				0.02

Note: PCM = phase contrast microscopy; TEM = transmission electron microscopy.
[A]Ratio of asbestos fibers to total fibers (f/F) by TEM.
[B]Total fiber concentrations by PCM were converted to PCM-asbestos concentrations using the fiber ratio reported from TEM analyses in accordance with NIOSH Method 7402.[13]
[C]Replicate 3 of the band sawing test was aborted due to band saw failure.
[D]Average calculated using the values shown (full detection limit for nondetect samples).
[E]Average calculated using half the detection limit for nondetect samples.

TABLE III. Summary of Results for Area Air Samples

Test	Replicate	PCM Total Concentration (f/mL)	TEM Data Asbestos Fibers	TEM Data Nonasbestos Fibers	TEM Data Ratio[A] (f/F)	PCM-Asbestos Concentration[B] (f/mL)
Band sawing[C]	a	0.04	22.5	4	0.85	0.04
	a	<0.04	12	4.5	0.73	<0.03
	a	<0.04	13.5	0	1.00	<0.04
	a	<0.04	18	6	0.75	<0.03
	b	0.08	8	3	0.73	0.06
	b	0.08	23	2	0.92	0.08
	b	0.07	12.5	2	0.86	0.06
	b	0.05	8	4	0.67	0.03
	c	0.35	10	1	0.91	0.32
	c	0.17	2	1	0.67	0.11
	c	0.12	12	3	0.80	0.10
	c	0.09	1	2	0.33	0.03
	Maximum	0.35				0.32
	Average[D]	0.10				0.08
	Average[E]	0.09				0.07
Background/ clearance[D]		0.004				0.001
Background/ clearance[E]		0.004				0.001
Belt sanding	a	0.07	5.5	4	0.58	0.04
	a	0.07	28.5	11	0.72	0.05
	a	0.06	30	5	0.86	0.05
	a	0.09	12	2	0.86	0.08
	b	<0.05	9	2	0.82	<0.04
	b	<0.05	15	10	0.60	<0.03
	b	<0.05	5	6	0.46	<0.02
	b	<0.05	24.5	5	0.83	<0.04
	c	0.06	4	1	0.80	0.05
	c	0.07	8	0.5	0.94	0.07
	c	0.08	10	10	0.50	0.04
	c	<0.05	4	0	1.00	<0.05
	d	0.05	7	4	0.64	0.03
	d	<0.05	4.5	2.5	0.64	<0.03
	d	0.08	9	1	0.90	0.07
	d	<0.05	16	10.5	0.60	<0.03
	Maximum	0.09				0.08
	Average[D]	0.06				0.04
	Average[E]	0.05				0.04
Background/ clearance[D]		0.002				<0.001
Background/ clearance[E]		0.002				<0.001
Press drilling	a	0.02	1	0	1	0.02
	a	0.02	0	0	0	<0.003
	a	<0.02	0	0	0	<0.003
	a	<0.02	0	1	0	<0.003
	b	<0.02	0	1	0	<0.004
	b	<0.02	0	1	0	<0.004
	b	<0.02	0	2	0	<0.004
	b	<0.02	0	0.5	0	<0.004
	c	<0.02	0	0	0	<0.004
	c	<0.02	0	0	0	<0.004
	c	<0.02	0	2	0	<0.004
	c	<0.02	0	1	0	<0.004
	d	0.02	0	1	0	<0.003
	d	0.02	1	0.5	0.667	0.01
	d	0.02	0	0	0	<0.003
	d	0.02	0	0	0	<0.003

(Continued on next page)

TABLE III. Summary of Results for Area Air Samples *(Continued)*

Test	Replicate	PCM Total Concentration (f/mL)	TEM Data: Asbestos Fibers	TEM Data: Nonasbestos Fibers	TEM Data: Ratio[A] (f/F)	PCM-Asbestos Concentration[B] (f/mL)
	Maximum	0.02				0.02
	Average[D]	0.02				0.01
	Average[E]	0.02				0.01
Background/ clearance[D]		0.003				<0.001
Background/ clearance[E]		0.003				<0.001
Sweep cleanup						
Sawing	a	0.04	1	1	0.50	0.02
Sawing	a	0.02	1.5	2	0.43	0.01
Sawing	a	0.03	3	3	0.50	0.01
Sawing	a	<0.02	5	3	0.63	<0.01
Sawing	b	<0.02	0	4	0.00	<0.003
Sawing	b	<0.02	3	2.5	0.55	<0.01
Sawing	b	<0.02	1	2.5	0.29	<0.01
Sawing	b	<0.02	3	2.5	0.55	<0.01
Sanding	a	<0.02	2	3	0.40	<0.01
Sanding	a	<0.02	0	1	0.00	<0.004
Sanding	a	0.02	3	1.5	0.67	0.02
Sanding	a	0.02	0	2	0.00	<0.004
Sanding	b	<0.02	9	5	0.64	<0.01
Sanding	b	<0.02	2	3	0.40	<0.01
Sanding	b	<0.02	3	2	0.60	<0.01
Sanding	b	<0.02	0	1	0.00	<0.003
Sanding	c	0.08	3	5	0.38	0.03
Sanding	c	0.06	0	5.5	0.00	<0.004
Sanding	c	0.05	0	3.5	0.00	<0.004
Sanding	c	0.06	3	9	0.25	0.01
Drilling	a	0.05	0	0	0.00	<0.004
Drilling	a	0.03	2	3	0.40	0.01
Drilling	a	0.03	0	0.5	0.00	<0.004
Drilling	a	0.02	0	0.5	0.00	<0.004
Drilling	b	0.04	1	4	0.20	0.01
Drilling	b	0.04	0	3.5	0.00	<0.004
Drilling	b	0.04	2	3	0.40	0.02
Drilling	b	0.03	1	3	0.25	0.01
Drilling	c	0.03	0	2	0.00	<0.004
Drilling	c	0.05	1	1	0.50	0.03
Drilling	c	0.07	2	3	0.40	0.03
Drilling	c	0.07	1	2	0.33	0.02
Drilling	d	<0.02	0	0.5	0.00	<0.004
Drilling	d	0.03	1	0.5	0.67	0.02
Drilling	d	0.02	0	0	0.00	<0.004
Drilling	d	0.02	0	0	0.00	<0.004
	Maximum	0.08				0.03
	Average[D]	0.03				0.01
	Average[E]	0.03				0.01
Background/ clearance[D]		0.005				0.002
Background/ clearance[E]		0.003				0.001

Notes: Background samples were collected between the sawing, sanding, and drilling tests and the sweep cleanup tests; clearance samples were collected before the sawing, sanding, and drilling tests. PCM = phase contrast microscopy; TEM = transmission elctron microscopy.

[A] Ratio of asbestos fibers to total fibers (f/F) by TEM.

[B] Total fiber concentrations by PCM were converted to PCM-asbestos concentrations using the fiber ratio reported from TEM analyses in accordance with NIOSH Method 7402.[12]

[C] Replicate 3 of the band sawing test was aborted due to band saw failure.

[D] Average calculated using the values shown (full detection limit for nondetect samples).

[E] Average calculated using half the detection limit for nondetect samples.

TABLE IV. Estimated 8-Hour Time-Weighted Average Concentrations

	Average PCM-Asbestos Concentration (f/mL)[A]				8-Hour TWA Concentration[B] (f/mL)	Maximum PCM-Asbestos Concentration (f/mL)[A]				8-Hour TWA Concentration[B] (f/mL)
Scenario	Sawing	Sanding	Drilling	Sweep Cleanup		Sawing	Sanding	Drilling	Sweep Cleanup	
A	0.11	0.04	<0.01	0.02	0.06	0.21	0.05	<0.01	0.08	0.08
B	0.11	NA	NA	0.02	0.03	0.21	NA	NA	0.08	0.06
C	NA	0.04	NA	0.02	0.03	NA	0.05	NA	0.08	0.06
D	NA	NA	<0.01	0.02	0.006	NA	NA	<0.01	0.08	0.01

Notes: The 8-hour time-weighted average concentrations were calculated assuming various scenarios of work activity:

A–For an 8-hour workday: 2 hours sanding, 2 hours sawing, 2 hours drilling, 1.5 hours sweep cleaning (remainder at background concentration).

B–For an 8-hour workday: 2 hours sawing, 1.0 hours sweep cleaning (remainder at background concentration).

C–For an 8-hour workday: 2 hours sanding, 1.0 hours sweep cleaning (remainder at background concentration).

D–For an 8-hour workday: 2 hours drilling, 1.0 hours sweep cleaning (remainder at background concentration).

PCM = phase contrast microscopy; TWA = time-weighted average; NA = not used in calculation of 8-hour TWA.

[A] Total fiber concentrations by PCM were converted to PCM-asbestos concentrations using the fiber ratio reported from transmission electron microscopy analyses in accordance with NIOSH Method 7402.[13]

[B] 8-hour TWA concentrations were calculated using the equation presented in the text.

with a 30-min lunch break, an 8-hour TWA can be calculated for someone who saws (2 hours), sands (2 hours), drills (2 hours), and performs sweep cleaning after each of these three activities for 30 min (1.5 hours total). This scenario assumed a background concentration (a nonzero concentration) for the 30-min lunch break, during which time no work would be performed. The calculated 8-hour TWA for this worst-case scenario (each of the three activities for 2 hours and sweeping for 1.5 hours, 30 min per activity) is calculated to be no greater than 0.08 f/cc using the maximum PCM-asbestos concentrations (Table IV). When using an average PCM-asbestos concentration for each activity for the same scenario, the calculated 8-hour TWA is 0.04 f/cc. Using a series of reasonable, hypothetical worker activity scenarios that assume different amounts of time spent conducting each activity during a hypothetical workday, a range of 8-hour TWA concentrations can be calculated using the equation shown in the Methods section. The range of calculated 8-hour TWAs is shown in Table IV. Using a variety of hypothetical activity scenarios, the calculated 8-hour TWAs range from 0.006 to 0.08 f/cc.

DISCUSSION

Thousands of products containing encapsulated asbestos fibers were manufactured in the United States and other countries between 1920 and 1980.[14,15] However, few studies have evaluated the potential health risks associated with exposure to asbestos-containing phenolic molding materials. In 1938, the presence of dermal folliculitis was observed in 10 molders.[16] No other health effects were noted and the skin irritation appeared only in the presence of extreme heat. A report in 1973 stated that asbestos dust might be generated during sawing, drilling, or other machining of formed asbestos-reinforced plastic products, thereby requiring precautions to be taken to ensure that dust generation was minimized;[17] however, no health effects were studied.

In 1993, Kogan et al.[18] studied the mortality rates of friction product workers exposed for at least 20 years to asbestos-containing dust, including asbestos dust generated during mechanical finishing (cutting, drilling, grinding, and polishing) of manufactured friction products. They found no excess cancer deaths in workers exposed to asbestos dust generated from machining products containing vulcanized rubber or phenol formaldehyde resins. As part of this study, Kogan et al. also injected asbestos dust from phenolic resin compounds intratracheally in rats. Results showed that the dust was only weakly tumorigenic, despite the high (greater than 50%) asbestos concentration. This low biological activity was attributed to the fact that the asbestos fibers were encapsulated by a rubber and phenol formaldehyde resin layer.

Due to the popularity of phenolic products in the 1950s through 1970s, and potential health concerns regarding asbestos exposure, a better understanding of the potential exposure of workers who handle these types of products is necessary. The test results from this study are useful in providing a sense of the possible exposures that historical workers may have experienced when they were engaged in sawing, sanding, or drilling of BMMA-5353 and other materials in this class of phenolic resins. The estimated 8-hour TWAs are considered near-upper-bound exposure concentrations (certainly on an annual average basis) because workers only rarely would have been engaged in the types of activities evaluated in this study, if at all. These manipulations are considered to be rare because the products were generally molded to fit, thereby precluding the need for additional manipulation (e.g., case for a radio, sheet of electrical board). Because of the encapsulating nature of finished products manufactured from phenolic molding materials and their nonfriable state, BMMA-5353 is similar to other encapsulated materials. Routine handling of the phenolic molding compounds by workers is not expected to generate a significant release of asbestos fibers because the fibers are tightly locked into the polymer matrix. During more aggressive manipulations, such as sanding, sawing, or drilling, some fibers are likely released.

The estimated 8-hour TWAs, which range from 0.006 to 0.08 f/cc, represent plausible upper-bound airborne concentrations for a worker performing sawing, sanding, drilling, and sweep cleanup of BMMA-5353 for 0.5 to 2 hours in an 8-hour workday. Based on these hypothetical scenarios, the mechanical manipulation of BMMA-5353 would not be expected to produce airborne concentrations of asbestos greater than current or historical standards set by OSHA and ACGIH® for worker protection. The estimated 8-hour TWAs are at least a hundredfold less than the OSHA PEL of 5 f/cc set in 1972, and fiftyfold less than the OSHA PEL of 2 f/cc effective in 1976.[12] Even under the current OSHA workplace standards, the estimated 8-hour TWAs for 0.5 to 2 hours of manipulation in an 8-hour workday would be at least threefold lower than the current OSHA PEL and ACGIH TLV® of 0.1 f/cc.[9,19] Based on these results, mechanical manipulations of phenolic molding compounds and cleanup of dust generated from the kinds of procedures evaluated here would not, under any reasonably plausible scenario, be expected to produce airborne concentrations of asbestos above historical or current 8-hour TWA occupational exposure limits.

ACKNOWLEDGMENTS

We appreciate the exceptional material sciences work performed by Chris Scott and John Moalli, who reformulated the material used for this study, and the Union Carbide Company, which manufactured phenolic molding compounds and funded this work.

We also acknowledge RJ Lee Group, Inc. for providing the indoor test chamber, performing the tests, and analyzing the samples, with special thanks to Boyd Clark and Drew Van Orden.

At least one of the authors has served as an expert in litigation involving the health hazards associated with exposure to asbestos and/or phenolic molding compounds.

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