INDUSTRIAL HYGIENE SUMMARY REPORT
OF
ASBESTOS EXPOSURE ASSESSMENT
FOR
BRAKE MECHANICS

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ABSTRACT

The National Institute for Occupational Safety and Health has conducted industrial hygiene surveys to characterize airborne asbestos exposures and work practices for brake mechanics. Personal and general area air samples were collected and analyzed for Time Weighted Average (TWA) and peak asbestos fiber concentrations. Bulk samples were collected and analyzed for asbestos fiber content and size. All samples were analyzed by optical (OPT) and transmission electron microscopy (TEM). The TWA and peak exposure levels varied with the assembly cleaning methods and time required to perform cleaning. Eight of thirteen TWA's for mechanics exceeded NIOSH recommended standards of 0.1 fibers/cc >5 um in length, (fibers/cc) but all were within current Occupational Safety and Health Administration regulations (2 fibers/cc). Fiber levels for all cleaning methods, except vacuuming, were near the NIOSH recommended ceiling, of 0.5 fibers/cc. Two of the peak samples collected when compressed air cleaning was used had fiber levels that exceeded the OSHA ceiling of 10 fibers/cc. General area TWA's were similar for all facilities (0.08 to 0.28 fibers/cc). TEM analysis indicated lower fiber concentrations than OPT in most samples and revealed that 80% of the total fiber population was <5 um long. The geometric mean chrysotile fiber size was 1.7 um length and 0.15 um diameter. TEM analysis showed that 30% of the fibers were chrysotile, 20% forsterite, and 50% unknown. The data show excessive asbestos fiber exposures during brake servicing, especially brake assembly cleaning; therefore, vacuum cleaning systems and NIOSH approved respiratory protection are recommended to reduce asbestos exposure levels within NIOSH limits.

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INTRODUCTION

One of the objectives of the National Institute for Occupational Safety and Health (NIOSH) is to evaluate environmental exposures of working populations through industrial hygiene field surveys. Accordingly, NIOSH conducted comprehensive industrial hygiene surveys to; characterize dust exposures resulting from vehicle brake servicing operations, make a thorough assessment of work practices utilized, and document the types of personal protective equipment used. Of particular interest was the potential for exposure to asbestos fibers which could be generated by these types of operations. Limited studies of workers involved in brake servicing have suggested that their work-related exposures may be associated with asbestos-induced diseases.[1]

NIOSH estimates that a work force of 151,000 brake mechanics and garage workers in the U.S. is potentially exposed to asbestos.[2] Potential exposures are a result of 128 million pounds of asbestos used annually in the U.S. for the production of brake friction materials.[3] Besides asbestos, other materials (e.g., binders, friction modifiers, fillers) are used in the manufacture of brake linings, that can likewise have a potential for exposure. As noted in one study, 30 materials and/or compounds that make up the binders, fiber reinforcers, property modifiers, etc., were identified during brake lining manufacturing.[2]

BRAKE MATERIALS, PRODUCTS, AND USAGE

Historical Development of Friction Products[4]

The requirements of early automobile friction materials were relatively minimal. Passenger cars were light and designed for low speed operations. Brakes were of an external contracting type and utilized a variety of materials; this included leather and impregnated cotton products which were commonly used along with wool and felt. In 1903 woven asbestos friction materials were first marketed in the United States by the Keasbey and Mattison Company of Ambler, Pennsylvania.[5] Because of their superior heat resistance and durability they rapidly increased in use and soon dominated the market. The woven asbestos brakes continued to be the dominant product used in automobiles until about 1930. They typically contained 70% or more wire-cored asbestos yarn impregnated with drying oils, such as linseed and bituminous material.

Molded brake linings were developed in the early 1920's and gained increasing use with the introduction of internal shoe brakes in 1927. By 1940 virtually all automobiles were equipped with molded brake linings, although woven products continue to be used in trucks, heavy equipment and for specialized applications. The molded linings in use were cut to length, usually by the manufacturer, and mounted on brake shoes using rivets. Until the mid 1920's brakes were only mounted on rear wheels; however, with the development of internal shoes, four wheel mountings soon became standard.

As automobiles were designed for use at higher speeds, brake linings improved in both quality and performance. Various new materials were introduced as fillers, binders, and friction modifiers. In 1948 bonded brake linings were developed and soon accounted for approximately 40% of the original equipment brake market. In addition, they rapidly dominated the replacement market because of the considerable savings in labor during installation. In 1965 the first disc brakes were introduced on American automobiles and rapidly increased in use. In 1975 virtually all original equipment cars had front wheel brakes of this type. However, because of less stringent braking requirements and the difficulty of adapting mechanical parking brakes to the disc configuration, the rear wheel brakes on 95% of currently sold cars are still of the drum variety.

Requirements for Brake Linings

A constant or slightly decreasing coefficient of friction (CF) with temperature up to about 1000 F is required for an efficient brake lining; CF values of from 0.30 to 0.45 are normally sought. Lower values produce brakes requiring excess pedal pressure, and those with higher values are too sensitive to pressure and develop excess wear. Ideally, the desired frictional qualities should be maintained throughout the life of the lining material. During braking, chemical and physical changes occur in the material at the braking surfaces. These changes may produce an increase (build-up) or a decrease (fade) in friction. Satisfactory linings will fade slightly upon repeated applications, but will return to their initial state upon cooling.[6]

Low wear of the linings is obviously desirable for economical and practical considerations. However, high wear resistance can be associated with the tendency of the lining to glaze, with a concomitant reduction in the CF. This can be overcome by allowing a slow alteration of the brake lining material to occur. Pyrolysis of the organic binders and thermal decomposition of the chrysotile fibers under braking provide the necessary continuing renewal of the lining surface.

The lining should be non-abrasive to the drum surface. In addition to causing rapid drum wear, abrasive linings score the drums which, in turn, leads to a rapid wearing of the lining. Drums made of cast iron and steel are common with steel being more susceptible to scoring. Since brake drums have a hardness of from 3.5 to 4.0 on the MOH (mineral hardness range of 1 to 15 in which talc is rated 1 and diamond 15) scale, virtually all lining materials used have lower hardness values.

Other necessary or desirable properties of brake linings include: physical strength, dimensional stability, quiet operation, and safe and non-offensive degradation products. Of the various properties desired in the linings, greatest attention is paid to build-up/fade and recovery characteristics. Wear problems are not as serious and can more readily be overcome with the materials available.

Compounding Ingredients of Brake Lining[7,8,9,10]

To achieve the desired friction properties, a wide variety of ingredients are commonly used in the manufacturer of automobile brake linings. These include:

Asbestos

Asbestos is used for fiber reinforcement of the friction product. Chrysotile is used almost exclusively and comprises from 40 to 50 percent of the brake lining. Fiber grades 4 through 7 are used, and occasionally, several sizes are mixed or even calcined to improve performance characteristics. Amosite, crocidolite, or other amphibole asbestos varieties are not used because they are too harsh and tend to score the brake drums.

Organic binders

Organic binders are primarily phenolic type resins selected for high binding strength. Unmodified phenolic resins when subjected to heat usually become hard and brittle. To prevent this, linseed, cashew nut, or China wood oils or cresols are added. Rubber, which also finds use as a binder, imparts desirable friction qualities and improves the flexibility of the lining material.

Friction modifiers

Friction modifiers are added to achieve a desirable CF over all operating conditions. These modifiers also produce a more homogeneous lining surface. Included among these materials are lead, zinc, brass, cashew nut oil, graphite, and oxides of iron and copper.

Fillers

Fillers such as rubber scrap, barites, clays, silica, coke, coal and other minerals are used. These also have utility in achieving desired friction properties, in some cases through action as abrasives to recondition braking surfaces. One major purpose of the reconditioning agents is to retard the formation of forsterite which may accumulate on the surface of the brake lining. Forsterite is a mineral not originally present in the brake material, but is created by dehydroxylation and recrystallization of chrysotile asbestos at high temperatures. The hardness of forsterite (6.5-7.0

on the MOH Scale) is such that it tends to score and gouge brake drums and discs (hardness 3.5), degrading them prematurely. Therefore, recrystallization of chrysotile to forsterite is an unwanted effect.

Curing agents

Curing agents and/or accelerators are used to assure that appropriate chemical reactions occur to produce the desired brake quality.

Types of Brake Linings and Manufacturing Processes

In the making of different types of brake linings various manufacturing processes are utilized to achieve a wide range of potential applications. These include:

Wired Back

These are made by a calendering process in which putty-like stock is formed into a ribbon about a wire backing. The wire reinforcing serves to maintain strength during the curing process. Furthermore, as linings of this type are invariably riveted, the wire reinforcing provides long term structural strength and prevents shearing of the lining at the rivets during braking. Linings of this type were extensively produced prior to World War II. They are in little use today.

Extruded Linings

These are manufactured by extruding the soft plastic stock through an appropriately sized rectangular orifice. To minimize structural weakness in this lining, curing agents are added to produce a hard inflexible finished products.

Sheet Linings

These are laminated structures formed by winding a 0.001-0.002 inch film of stock about a hot roller. Since the fabrication process is a relatively expensive one, linings of this type are not commonly produced for general use.

Dry Mixed Types

This process involves the dry mixing of various ingredients capable of passing a 200 mesh screen, and then molding the lining under pressures of from 1000 to 3000 pounds per square inch. The resulting lining is among the most heat stable of friction materials in use today and obtains wide use in the manufacture of brake blocks for heavy duty service.

Millboard Type

The manufacture of this type of brake lining material is by a process similar to that utilized in the paper industry. Wet stock is formed and passed over rollers with various drying and baking operations producing sheets of uniform lining material. The equipment for producing such materials is expensive, but the volume of production leads to an economically produced molded lining.

BRAKE LINING REPAIR AND MAINTENANCE PRACTICES HISTORY

To a large extent the changing character of brake lining materials has led to changing work practices and differing asbestos exposures over the years. From 1920 until about 1930, when braking was done through the use of external brake bands made from woven materials, the predominant exposure to asbestos would have come from the cutting and fitting of the woven lining material. Most likely the airborne fiber concentrations were considerably less than those developed in later years when machining of molded materials was common.

From 1927, when internal brake shoes were developed using molded linings, until 1948 when bonded brake linings were introduced, all internal brake linings were attached to shoes using rivets. The lining material for use in the replacement market would be precut to appropriate size for various brakes or obtained from rolls of indeterminate length. The precut segments would usually be predrilled at the factory for rapid mounting on shoes. In some circumstances, however, drilling for the rivets and bevelling would be done by the mechanic installing them. The use of rolled linings required cutting the friction material to shape, drilling holes for rivets, and bevelling the edges appropriately. Under the latter circumstances, asbestos exposure to workers could be considerable. Even when shoes with predrilled and bevelled linings were installed, the processes of punching out the rivets on the old shoes and riveting on of the new shoes would give rise to greater exposures than that accompanying the use of bonded linings.

With the introduction of bonded lining, the need for drilling, facing, or grinding operations during installation decreased significantly. However, for a short period of time, in the mid-1950's when automobile shoes were first installed with a fixed anchor, some tapering was necessary on uniform thickness bonded linings to achieve a proper fit. Previously, the end of the shoe opposite to that of the hydraulic cylinder could be mechanically adjusted. Shortly thereafter, tapered bonded linings were available from the factory. Subsequent to 1960, considerably fewer bevelling or grinding operations were performed by an automobile mechanic replacing brake linings.

During replacement of internal shoe brakes common practice was to remove the brake wear dust from the housing by air blowing or brushing. After 1970 increasing awareness of the hazards of asbestos and its presence in brake-lining dust led to wet brushing, wet wiping, dry brushing, or vacuuming work practices in some brake servicing facilities. However, even today such improved work practices are not universal.

In the 1930's and 1940's most automobile shops were relatively small and most mechanics performed all automobile maintenance and repair activities. In recent years, however, there has been an increasing tendency towards specialization, with shops existing for brakes and front end work exclusively. Here, while asbestos exposures during brake work on an individual job may be less than those of previous years, some workers are exposed for considerably longer periods of time.

SELECTION OF FACILITIES SURVEYED

The purpose of the industrial hygiene study was to investigate and characterize contemporary dust exposures resulting from vehicle brake maintenance and repair operations taking into account the work practices utilized. Therefore, it was necessary to locate facilities where a variety of brake servicing techniques were used as well as where there were differences in the number of vehicles serviced. Two of the six sites selected for the investigation were automobile brake service facilities which performed up to 45 brake jobs per week at an average of 65 minutes per vehicle. The remaining four facilities serviced both autos and trucks and performed from 5 to 45 brake jobs per week. The service time varied depending on the type of vehicle. Detailed airborne dust sampling surveys were conducted at each facility.

DESCRIPTION OF BRAKE SERVICING OPERATIONS

The servicing procedures found at each facility were basically as follows. The vehicle is driven into a repair stall or bay for a brake system examination. Pending repairs, the wheels are elevated, removed, and then inspected. Loose dust is cleaned from the drums and brake assemblies by vacuuming, wet or dry wiping/brushing, using compressed air, or a combination of these methods. Parts are then replaced or repaired as needed and the brake system is reassembled and adjusted. Test driving the vehicle for proper fitting and adjustment is the final phase of the servicing operation. A brief description of the individual facilities is outlined in Appendix B.

SAMPLE COLLECTION AND ANALYSIS METHODS

Airborne Samples

Personal and general air samples were collected at each facility on different occasions during a 3-year period. Brake servicing operations and areas not in the immediate vicinity of brake work within each facility were monitored to provide overall asbestos exposure data. Personal air samples were collected in the breathing zone of the brake mechanics using plastic cassettes containing Millipore Type AA, 37 millimeter (mm) diameter, 0.8 micrometer (μm) pore size, membrane filters. The samples were operated at a calibrated sampling flow rate of 2.0 Liters per minute (Lpm). The filters were changed periodically during the work shift to prevent particulate overloading on the filter. Time-weighted average (TWA) fiber concentrations were determined for the time spent performing brake service, and peak concentrations were determined for time spent cleaning brake dust from drums and assemblies. Samples for personal peak exposures were collected using Gast pumps calibrated at about 11.0 Lpm using identical media as above. At facilities C, D, and E, a 2.0 Lpm sampling train was used for peak samples. All analyses of the membrane filters for asbestos fibers were conducted by the author in accordance with the procedures outlined by the Occupational Safety and Health Administration[11] and the NIOSH Manual of Analytical Methods P&CAM #239.[12] These procedures require the counting of fibers greater than 5 μm in length and with at least a 3 to 1 length to width aspect ratio utilizing phase contrast optical microscopy at a magnification of 400-450X. Concentrations are expressed as fibers per cubic centimeter of air (fibers/cc).

Random samples from each facility surveyed, as well as those samples having high fiber concentrations, as determined by the optical counting method, were analyzed on a transmission electron microscope (TEM) utilizing selected area electron diffraction (SAED) and energy dispersive X-ray analysis (EDXRA). Samples were observed at 17,000X magnification with fibers ($\geq$ 3:1 aspect ratio) sized by length and diameter. SAED was attempted on all observed fibers for identification. In addition, EDXRA was performed on individual fibers to determine their elemental composition. SAED patterns and EDXRA elemental spectrum ratios were compared with reference minerals (chrysotile and forsterite obtained from the U.S. Smithsonian Institution). Sample preparation and analysis were performed using the method described in the Technical Report "Review and Evaluation of Analytical Methods for Environmental Studies of Fibrous Particulate Exposure".[13]

General area samples for trace metals (lead, zinc, copper, iron, and manganese) were collected at most facilities using Staplex Type TF-1A high-volume samplers at a flow rate of 10 cubic feet per minute, and also with a sampling train and flow rate like that used for asbestos fiber collection. Samples were analyzed for metals by atomic absorption spectrophotometry in accordance with the NIOSH methods P&CAM Number 222, S186, S341, and S366.[14,15]

Bulk Samples

Samples of brake wear dust were collected from the brake drums of several vehicles that were being serviced during the surveys. These samples were analyzed by TEM for characterization and identification of fibrous particulates and for determination of fiber size distributions.

WORK PRACTICE CHARACTERIZATION

During the surveys considerable emphasis was placed on detailing work procedures during brake servicing in order to document the types of cleaning practices (e.g., vacuum, compressed air, brushing) used in replacing brakes. As previously described in the section "Description of Brake Servicing Operations" the brake servicing work practices utilized were similar for all facilities surveyed; the major difference observed was the methodology utilized for clean-off of brake wear dust from the brake-shoe/backing-plate assemblies. There were six different types of clean-off methods observed during the study. Those six methods are described as follows:

1. Compressed Air Blow-Off. A compressed air stream was used to blow away brake wear dust from the brake assemblies and drums.

2. Compressed Air-Stoddard Solvent Mist Blow-Off. The same as #1 except a spray gun containing stoddard solvent was used to produce a solvent mist for blow-off.

3. Dry Brushing. Brake wear dust was brushed away with a small utility brush usually 1 inch in diameter.

4. Wet Brushing. Basically the same as dry brushing except the brush was kept saturated with a liquid such as gasoline, water, or stoddard solvent.

5. <u>Squirt-Off.</u> A liquid squirt-bottle containing water was used to wash away brake dust. This was followed by drying off assemblies with a cloth.

6. <u>Vacuum Cleaning.</u> A shop type vacuum cleaner, equipped with a HEPA filter*, was used in combination with compressed air. This system included a brake encapsulation cylinder that completely enclosed the brake-shoe/backing plate assembly. The mechanic operated a compressed air nozzle fixed inside the enclosure to blow off the brake dust, which was immediately drawn into the vacuum system. A separate vacuum hose was used to vacuum the dust from the brake drums.

*HEPA: High Efficiency Particulate Air Filter - 99.7% efficiency for 0.3 μm diameter aerosols.

In Methods 1 to 5, and especially 1 to 3, the brake dust has the potential to enter the ambient air of the facility. Conversely, in Method 6 the dust is contained by the HEPA filter which may be removed from the vacuum cleaning system for disposal.

SURVEY RESULTS AND DISCUSSION

Asbestos Exposure Levels

The optical microscopy fiber count analysis for the TWA, peak personal, and background area samples collected during the study are summarized in Table 1. The TWA concentrations ranged from 0.0 to 0.28 fibers/cc while peak levels ranged from 0.00 to 15.00 fibers/cc. The TWA and peak fiber exposures for mechanics tended to fluctuate. This is perhaps best explained by variations in work practices utilized, the inconsistencies in performing brake work that existed throughout the various repair shops, and because clean-off is done intermittently and therefore represents a small percent of the work performed during the shift. For example, the amount of time spent servicing brakes and the number of brake jobs that were performed per shift differed among the mechanics; likewise, there were differences in cleaning methods (e.g., compressed air, brush, vacuum), and procedural techniques (e.g., distance from brake housing to breathing zone). In addition, there were some mechanics who dropped the brake drums on the floor, causing airborne dispersal of brake dust. Environmental conditions at each brake service facility such as shop size, ventilation controls, and open windows and doors would also affect individual worker exposure and background concentrations of airborne asbestos fibers.

Regardless of the cleaning method utilized, TWA exposures for mechanics at all facilities were consistently less than 0.1 fibers/cc and did not differ much from TWA fiber concentrations for samples collected in the mechanics general work area. The similarities between mechanic TWA exposures and background fiber concentrations suggest that all individuals in the

Table 1

Fiber Air Sample Results for Brake Assembly Clean-Off Methods

Cleaning Method	Facility Surveyed	Employee Sampled	Peak Exposures			TWA Exposures**			General Area TWA Concentrations		
			Fibers/ cc*	Sample Time (Sec.)	Sample Volume (Liters)	Fibers/ cc*	Sample Time (Min.)	Sample Volume (Liters)	Fibers/ cc*	Sample Time (Min.)	Sample Volume (Liters)
Compressed Air	A	Mechanic #1	1.82	180	6.0						
Compressed Air	A	Mechanic #1	0.14	38	4.7						
Compressed Air	A	Mechanic #1	0.77	34	4.2	0.03	352	704	0.013	380	760
Compressed Air	A	Mechanic #1	0.35	26	3.2						
Compressed Air	A	Mechanic #1	2.69	20	2.5						
Compressed Air	B	Mechanic #1	2.84	60	10.7	0.12	283	566	0.10	133	266
Compressed Air	B	Mechanic #2	0.91	45	8.0						
Compressed Air	B	Mechanic #2	14.54	30	5.3	0.10	298	596	0.08	227	454
Compressed Air	B	Mechanic #3	15.00	30	5.3	0.19	270	540	0.13	94	188
Compressed Air-Solvent Mist	B	Mechanic #1	0.25	60	4.0						
Compressed Air-Solvent Mist	B	Mechanic #1	0.45	45	8.0	0.08	343	686	0.04	231	462
Compressed Air-Solvent Mist	B	Mechanic #2	0.68	30	5.3						
Compressed Air-Solvent Mist	B	Mechanic #2	0.37	180	12	0.07	283	566	0.03	222	444
Dry Brush	C	Mechanic #1	0.81	720	24	0.20	197	394	0.07	414	828
Dry Brush	C	Mechanic #2	0.61	1260	42	0.19	301	602	0.03	382	764
Wet Brush	D	Mechanic #1	2.62	180	6.0	0.23	346	692	0.07	360	720
Wet Brush	D	Mechanic #2	2.22	180	6.0						
Wet Brush	D	Mechanic #2	0.87	540	18	0.28	369	738	0.07	360	720
Wet Brush	D	Mechanic #3	0.67	540	18	0.24	135	270	0.07	360	720
Liquid Squirt Bottle	E	Mechanic #1	0.54	600	20	0.21	326	652	0.06	395	790
Vacuum Cleaning	F	Mechanic #1	0.00	120	16						
Vacuum Cleaning	F	Mechanic #1	0.07	120	16						
Vacuum Cleaning	F	Mechanic #1	0.03	120	16	0.01	240	480	0.01	378	756

* Fibers >5 μm in length per cubic centimeter of sampled air.
** Time-Weighted Average exposure for period of time sampled.

immediate work environment are potentially exposed to the same fiber concentrations during a normal work shift. This observation is further supported by the fact that several of the mechanics monitored spent much of the work shift away from the work site, but had TWA exposures similar to those that spent most of the shift at the site.

TEM Fiber Characterization

Samples were randomly selected for transmission electron microscopy (TEM) with fibers sized by length and diameter and 10 fields were analyzed for eeach sample. In addition, fiber concentrations (fibers/cc) were determined for total fibers and fibers $> 5\ \mu m$ in length. These concentrations were compared to those found by the optical microscopy method and are reported in Table 2. In all but three samples, the concentrations of fibers $> 5\ \mu m$ in length determined by optical microscopy were slightly higher than those determined by TEM. This difference was probably the result of several factors. These include: particulate loss during sample preparation for TEM, asbestos fibers are counted by TEM while this selectivity is not possible with optical microscopy, and the small number of fibers actually counted on each sample. At low fiber counts, small differences in the number of fibers counted by each microscopy method has a significant effect on the calculated result of the fiber concentration. Statistical comparison of the TEM and optical microscopy counting methods was not attempted because of the disparity in the capabilities of the two methods. Besides determining the concentrations for fibers $> 5\ \mu m$ in length, total fibers observed were counted and concentrations calculated. As would be expected, the greatest proportion of fibers observed was shorter than $5\ \mu m$ in length (80 to 90%).

Table 2

Air Sample Results For Fibers
Comparison Between TEM and Optical Microscopy Analyses

Optical Microscopy	Transmission Electron Microscopy *		
>5 μm in length fibers/cc	>5 μm in length fibers/cc	Total Fibers fibers/cc	% Fibers >5 μm in length
0.54	0.25	0.50	50
6.0	5.97	11.33	53
0.58	0.17	1.01	17
1.18	0.67	2.35	29
0.13	0.10	0.74	14
6.84	0.07	0.43	17
5.59	0.33	0.39	83
0.82	0.02	0.02	100
0.01	0.0	0.11	0
0.01	0.0	0.0	0
0.02	0.19	2.72	14
0.38	0.16	0.48	33
1.44	0.0	0.08	0
0.01	0.0	1.43	0
0.26	0.09	0.09	100
0.24	0.04	0.16	25
0.06	0.0	0.0	0
0.12	0.01	0.01	100
0.01	0.0	0.03	0
0.03	0.0	0.0	0
0.0 (Blank)	0.0	0.0	0
0.12	0.42	0.86	48
0.17	0.10	0.20	50
0.18	0.14	0.43	33
0.06	0.05	0.15	33
0.12	0.50	0.73	68

* Note: Fibers counted by TEM represent asbestos fibers only.

Fibers observed by TEM were identified utilizing SAED and EDXRA. Approximately 50% of the fibers analyzed by SAED could not be identified due to ambiguous diffraction patterns. About 30% of the fibers were identified as chrysotile and approximately 20% as forsterite. The presence of fibrous forsterite was probably due to the dehydroxylation and recrystallization of chrysotile as a result of high temperatures (>650° C) encountered during braking.[1,2] Some of the fibers which revealed ambiguous diffraction patterns appeared to have crystalline structures similar to both chrysotile and forsterite (probably a transition intermediate[2]) while others were too small for diffraction analysis. EDXRA was performed on the fibers to confirm the SAED analysis that was made for the chrysotile and forsterite fibers. Some of those fibers which gave ambiguous SAED patterns indicated magnesium, silicon, and iron in various elemental ratios typical of asbestiform minerals.

As shown in Table 3, when a fiber size distribution was performed for all airborne sample fibers observed by TEM, a geometric mean length of 1.66 μm and a geometric mean diameter of 0.14 μm were determined. Likewise, for those fibers identified as asbestos (chrysotile) a geometric mean length and diameter of 1.70 μm and 0.15 μm, respectively were determined.

Bulk samples of brake wear dust were analyzed by TEM in the same manner as the airborne samples. Identification was attempted on all fibers using SAED and EDXRA. Approximately 70% of the fibers analyzed by SAED could not be identified due to ambiguous or the absence of diffraction patterns. EDXRA was performed on all fibers observed with elemental analysis being success-

TABLE 3

Brake Dust Fiber Size Data*

		Fiber Diameter (um)				Fiber Length (um)		
SAMPLE TYPE	Number of Fibers	Range	Geo. Mean	Geo. Std Dev**	Number of Fibers	Range	Geo. Mean	Geo. Std Dev
Airborne Samples Chysotile Fibers Only)	151	0.06-1.0	0.15	2.36	151	0.24-10.0	1.70	2.27
Airborne Samples (All Fibers)	523	0.06-1.0	0.14	2.17	523	0.24-10.0	1.66	2.49
Bulk Brake Dust Chysotile Fibers Only)	8	0.06-0.18	0.10	1.53	8	0.24-1.76	0.40	2.03
Bulk Brake Dust (All Fibers)	109	0.06-0.29	0.08	1.53	109	0.24-5.88	0.49	1.95

* All fiber size data determined by Transmission Electron Microscopy.
** Standard Deviation

ful on about 70% of the fibers. When utilizing SAED and/or EDXRA several of the fibers observed were positively identified as chrysotile (∿10%) while the remaining were either forsterite (∿20%) or unknown (∿70%). Many of the unknowns were thought to be intermediate recrystallized forms between chrysotile and forsterite. In addition, a fiber size distribution was performed which indicated somewhat shorter lengths (0.24-5.9 μm vs. 0.24-10 μm) and smaller diameters (0.06-0.29 μm vs. 0.06-1.0 μm) than those observed in the airborne samples in Table 3.

Trace Metal Analyses

Trace metal analyses were performed on airborne samples collected at Facilities B, C, D, and E with the results reported in Table 4. Samples were analyzed for the following metals: lead, iron, zinc, copper, and manganese, with analytical limits of detection of 5.0 ug, 1.0 ug, 0.6 ug, and 1.0 ug per sample, respectively. As noted in Table 4 the metals were often non-detectable (ND) or found in trace amounts, and only facility B had a metal concentration (Pb) that exceeded OSHA or NIOSH exposure standards. The range of concentrations for all facilities were: Pb, ND - 63.3 $\mu g/m^3$; Fe, ND - 2,300 ug/m^3, Zn, ND - 352 $\mu g/m^3$; Cu, ND - 8.7 $\mu g/m^3$; and Mn, ND - 3.5 $\mu g/m^3$.

Table 4

Trace Metal Analyses

Facility Surveyed	Range of Trace Metal Concentrations (μg/m^3)				
	Pb	Fe	Zn	Cu	Mn
B	N.D. - 63.3	N.D. - 349	N.D. - 351	N.D.	N.D.
C	0.4 - 0.6	1,500 - 1,800	0.3 - 0.5	0.1 - 0.2	0.03 - 0.04
D	19.5 - 24.9	1,200 - 1,400	0.3 - 0.3	0.2 - 0.2	0.04 - 0.05
E	1.2 - 8.7	1,700 - 2,300	0.2 - 0.3	0.2 - 0.3	0.04 - 0.06
	OSHA Exposure Standard (μg/m^3)				
	50		5,000	1,000***	5,000****
	NIOSH Recommended Standard (μg/m^3)				
	100	-	5,000	-	-

N.D. - Not Detected by Analysis
* - Iron Oxide Fume
** - Zinc Oxide Fume
*** - Copper Dusts and Mists
**** - Ceiling

Limit of Detection (ug) Per Sample

Lead	5.0 ug
Iron	5.0 ug
Zinc	1.0 ug
Copper	0.6 ug
Manganese	1.0 ug

POTENTIAL HEALTH EFFECTS FROM ASBESTOS EXPOSURE

The human toxicological significance for the inhalation of chrysotile asbestos fibers is well documented; and instances of mesothelioma in auto repair workers have been identified.[16,17,18] In a detailed examination of 90 union vehicular maintenance workers in New York City,[1] with 10 or more years of shop work, 29% had decreased vital capability; the percentage increased with age and most markedly after 20 years from the outset of auto work. Many of the workers examined showed signs consistent with asbestosis, with observed changes noted in chest x-rays and indication of restrictive pulmonary function. The prevalence of these changes was significantly higher after 20 years exposure, a result expected after occupational exposure to asbestos.[19]

Unlike chrysotile, the health effects of exposure to forsterite, or transition series fibers (chrysotile/forsterite) with altered crystalline structures are not well documented. In studies by Davis and Coniam,[20] and Koshi[21] in which fibers of chrysotile, chrysotile/forsterite, and forsterite were injected into the pleural and peritoneal cavities of mice, the results suggested varying degrees of toxic effects. Fiber implantation animal studies conducted by Pott, et. al.[22,23] and Davis, et. al.[24] suggest that the morphology and size of a fiber, regardless of fiber type, are responsible for its carcinogenicity. Likewise, Stanton, et. al.[25] suggests that fibers <1.5 μm in diameter and >8 μm in length pose the greatest risk in producing pleural sarcomas. These studies tend to suggest that the physical morphology (size dimensions) and to a lesser degree chemical and surface characteristics of a fiber are the determining factors for inducing a biological effect. The precise fiber dimensional characteristics required for these observed pathologic responses have been difficult to determine experimentally because of the difficulties encountered in producing fibers of specific size dimensions.

SUMMARY

The TWA airborne asbestos sample results for all facilities were within the current OSHA asbestos standard.[26]

However, two of four peak sample results for samples collected at Facility B (Table 1) during the compressed air cleaning of brake assemblies exceeded the OSHA ceiling standard. The compressed air cleaning method also indicated the highest overall peak exposures (up to 15 f/cc) for all cleaning methods examined.

When the overall TWA sample results are compared to the NIOSH recommended standard for asbestos, 8 of 13 of the TWA exposures for mechanics indicated concentrations exceeding the recommendation. The NIOSH standard recommends an 8-hour TWA exposure of 0.1 fibers > 5 µm/cc (fibers/cc) with a ceiling exposure of 0.5 fibers/cc for any 15-minute sampling period. Peak sample results could not be compared directly to the NIOSH standard since they were not collected over 15-minute periods.

Many of the samples collected yielded such low fiber counts that their coefficient of variation (CV_t) was above what is considered reliable (i.e. greater than 0.38).[27] Consequently, the fiber concentration data are best utilized for comparing exposure variations among the different cleaning methods/work practices.

CONCLUSION

The results of this and other studies[1,2] indicate varying concentrations of asbestos fiber exposure to brake mechanics. The exposure concentrations are apparently affected by the work practices utilized and the existing environmental conditions and controls at each facility. The results of this study show that 8 of 13 of the mechanics engaged in brake service had TWA fiber exposures above the NIOSH recommendation. However, all TWA exposures were below the OSHA standard. Furthermore, when samples were analyzed by TEM, only 30% of the fibers observed were identified as asbestos with the remaining fibers being categorized as forsterite (20%) or unknowns (50%). As a result of the TEM analysis the levels of the asbestos concentrations (>5 μm length), as determined by optical microscopy, may be less than those reported (see Table 2). However, this does not preclude the possibility of higher airborne asbestos fiber concentrations when all fiber size ranges are considered. As determined by the TEM analysis in this study and from other reported studies,[28,29] a significant number (up to 100%) of short fibers (<5 μm in length) are usually present (see Table 2) and research [25] has indicated that a potential health risk exists for asbestos fibers <5μm in length. Also, a potential health risk may exist for the unknown fibrous portion (∿50%) of brake dust. The results of animal studies in which various size fibers were implanted in animals [22,23,24,30] concluded that the physical morphology (size dimensions) and, to a lesser degree, chemical and surface characteristics of a fiber are the determining factor for inducing a biological effect.

The mechanics surveyed during this study were either full-time brake mechanics, who performed only brake maintenance service and may have serviced up to 5 cars per day/6 days a week, or mechanics who undertook as few as one brake job per week. Regardless of the number of brake jobs performed (per work shift), the TWA fiber exposures were similar for all the mechanics surveyed. The exposures to mechanics who performed full-time brake work were not significantly higher than the exposures for those who did much less brake servicing. Conversely, the short term (<3 minutes) peak exposures encountered in this study during the dust clean-off of braking assemblies were often higher when compressed air was used. All of the cleaning methods surveyed, except for vacuum cleaning, had peak fiber concentrations that were near or above the NIOSH-recommended ceiling exposure level of 0.5 fibers/cc. However, the compressed air cleaning method was the only type which approached, and in two cases even exceeded, the OSHA ceiling exposure limit of 10 fibers/cc. These findings strongly indicate that brake mechanics are at a higher risk of airborne exposure to asbestos fibers during the cleaning of brake assemblies, except when the vacuum cleaning methods are properly utilized.

The samples collected for trace metals had concentrations that were within the OSHA and NIOSH exposure standards in all but one case. One area sample collected at facility B indicated a lead concentration of 63.3 ug/m^3 which exceeded the OSHA standard of 50 ug/m^3, but was below the NIOSH recommended standard of 100 ug/m^3.

RECOMMENDATIONS

The data from this study show that airborne fiber exposure exists during brake servicing operations, especially during brake assembly cleaning. While the fiber exposures reported do not represent 100% asbestos fiber, a potential health hazard still exists since at least 30% of the fibers are asbestos. Also, the other fiber types may be pathogenic since animal studies suggest that fiber shape and size may be more important than chemical nature in terms of biological activity, and the possibility exists for exposure to much higher asbestos fiber concentrations for fibers <5 μm length. Since there is no known safe asbestos fiber exposure level[31], and clinical evidence from a study of union vehicular maintenance workers reports that over 25% had evidence of x-ray abnormalities consistent with asbestosis, the prudent conclusion is that a potential health hazard exists during the performance of brake maintenance operations. Therefore, appropriate control measures for reducing fiber exposures, especially during brake assembly cleaning, should be instituted at brake maintenance facilities. This would best be accomplished by using an appropriate vacuum cleaning system to remove all dust from brake assemblies and drums. Above all, any blow-off of brake dust by compressed air must be eliminated. To further protect the health of the brake mechanics, a personal respiratory protection program should be initiated. This would include the wearing of NIOSH approved respirators for asbestos, a program for proper fitting, and a routine maintenance program for respirator cleaning and the replacing of filters. The peak vs TWA exposure data indicates that it would only be necessary for mechanics to wear respirators while performing brake assembly cleaning. In order to minimize asbestos dust exposures to vehicular mechanics performing brake and clutch maintenance NIOSH has prepared guidelines titled "Recommended Procedures for Asbestos Brake and Clutch Servicing" (see Appendix C) to be utilized during these types of work tasks.

APPENDIX A

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APPENDIX B

Description of Facilities Surveyed

Facility A

Major services at Facility A, an automobile brake service shop, consisted of front-end alignment. shock absorber servicing, and brake maintenance. The normal work week was made up of five, 9-hour days and one 6-hour day.

Facility B

Facility B was the largest of the automobile brake service shops surveyed. Other services provided by this facility were front-end alignment and shock absorber replacement or repair. The five full-time mechanics worked from four service stalls, 9 hours per day, 6 days per week. Brake maintenance operations consisted of 35 to 45 jobs per week.

Facility C

At Facility C, a municipal garage, an average of eight brake jobs per day were performed on cars and trucks. Brake maintenance was performed by any of the 60 auto mechanics. The hours of operation were 8 hours per day, 5 days per week.

Facility D

At Facility D, a municipal garage, there was an average of one complete brake service job per day, taking about 5 hours per job, with most of the vehicles consisting of cars or light trucks. There were five employees responsible for brake servicing and the facility operated 8 hours per day, 5 days per week.

Facility E

Facility E, a municipal service garage, employed three mechanics that specialized in brake and clutch service and three employees that operated a separate brake repair shop specializing in brake shoe and drum reconditioning. The brake mechanics serviced all vehicles which included, waste collection, dump and light trucks, autos, and some 2- and 3-wheeled vehicles. The shop operated 8 hours per day, 5 days per week.

Facility F

Facility F, a private fleet service garage, performed complete automotive and light truck maintenance. The shop normally operated two shifts, 5 days per week, and there were usually four full-time mechanics per shift. About one brake job week, per shift was performed.

APPENDIX C

RECOMMENDED PROCEDURES FOR ASBESTOS BRAKE AND CLUTCH SERVICING

The National Institute for Occupational Safety and Health (NIOSH) has conducted research on dust exposures which are generated during brake and clutch servicing. Based on data demonstrating the potential for significant asbestos exposures during brake and clutch servicing, NIOSH has investigated various work practices which are utilized in reducing asbestos exposures. These investigations have indicated vacuum cleaning systems to be the most effective method for minimizing asbestos dust exposures during brake and clutch servicing.[1] Vacuum cleaner testing have demonstrated that these units operate reliably within design specifications.[2] Therefore, NIOSH recommends vacuum cleaning as the primary method to be used for cleaning of asbestos dust during brake and clutch servicing operations.

The following are additional procedures recommended by NIOSH to minimize asbestos dust exposures:

1. Where possible, an area shall be designated for brake and clutch repairs and servicing. Entrances into this area shall be posted with the following asbestos exposure warning sign printed in letters of sufficient size and contrast to be readily visible and legible:

   Asbestos

   Dust Hazard

   Avoid Breathing Dust

   Wear Assigned Protective Equipment

Do Not Remain in Area Unless Your Work Requires It

Breathing Asbestos Dust May Be Hazardous to Your Health

2. Dust shall first be cleaned from brake drums, brake backing plates, brake assemblies, and clutch assemblies using an industrial type vacuum cleaner equipped with a high efficiency particulate air filter system (HEPA-greater than 99% efficiency for 0.3 μm diameter aerosols). After vacuum cleaning, any remaining dust shall be removed using a water dampened cloth or rag. Under no circumstances shall compressed air or a dry brush be used for cleaning. If vacuum cleaning equipment is not available the wet brush cleaning method may be used until a vacuum cleaning system is obtained. Where wet brushing is necessary for cleaning, a NIOSH certified respirator approved for asbestos shall be worn.

3. During brake pad grinding, riveting, and punching operations local exhaust ventilation and dust collection systems shall be designed, installed, and maintained in accordance with the American National Standard Fundamentals Governing the Design and Operation of Local Exhaust Systems, ANSI Z9.2 - 1977 to meet the asbestos airborne exposure standard.

4. During clutch servicing, a NIOSH certified respirator approved for asbestos shall be worn during the removal and cleaning of the clutch, pressure plate and housing assembly, and during installation of the new clutch assembly. Whenever possible, cleaning shall be performed with an HEPA vacuum system as described in (2) above.

5. All table and floor cleaning in areas where brakes and clutches are repaired shall be done with the HEPA vacuum cleaner as described in (2) above. Grinding and riveting machines shall also be cleaned with such a cleaner and the remaining dust wiped with a water dampened cloth. A NIOSH certified respirator approved for asbestos shall be used during this cleaning.

6. If not in effect, a respirator program shall be established in accordance with the Occupational Safety and Health Administration (OSHA) Standard, Title 29, U.S. Code of Federal Regulations (CFR), Part 1910.134.

7. HEPA vacuum cleaner filters containing asbestos dust, cloths or brushes used for wiping brake and clutch assemblies, and all liquid used for wet brushing shall be disposed of in accordance with U.S. Environmental Protection Agency (EPA) regulations. These regulations state that the asbestos waste shall be disposed of in sealed impermeable bags or other containers at a disposal site which meets EPA criteria for asbestos disposal. Also, the waste containers shall display the following warning label or tag printed in letters of sufficient size and contrast to be visible and legible:

CAUTION
Contains Asbestos Fibers
Avoid Breathing Dust
Breathing Asbestos Dust May Cause Serious Bodily Harm

The EPA regulations for proper asbestos waste disposal are detailed in Title 40, CFR, Part 61, Subparts A and B.

8. A NIOSH certified respirator approved for asbestos shall be worn during removal of vacuum bags which contain asbestos dust.

9. Consumption of food and beverages shall not be permitted in work areas where asbestos exists. An area designated for food consumption shall be separate from the work area so as to provide maximum protection against asbestos dust contamination.

10. If the employee is exposed to airborne concentrations of asbestos fibers which exceed the OSHA ceiling level, the OSHA requirement regarding special clothing, change rooms, locker, etc. as detailed in Title 29, CFR, Part 1910.1001 (D) shall be followed.

The OSHA asbestos standard as of July , 1976 states: the 8-hour time-weighted average (TWA) airborne concentrations of asbestos fibers to which any employee may be exposed shall not exceed 2 fibers, longer than 5 micrometers in length per cubic centimeter of air (fibers >5 μm/cc). The ceiling airborne concentration to which no employee may be exposed shall not exceed 10 fibers >5 μm/cc.

OSHA in 1975 proposed an 8-hour TWA of 0.5 fibers >5 μm/cc with a permissible ceiling exposure of 5 fibers >5 μm/cc for any period not exceeding 15 minutes. NIOSH currently recommends that the TWA exposure to asbestos be 0.1 fibers >5 μm/cc with a ceiling exposure of 0.5 fibers >5 μm/cc for any 15-minute sampling period.

NOTE: Strict adherence to the above procedures should minimize exposures to employee during brake and cluth servicing. These recommendations are based on the results of research conducted by NIOSH.

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