Asbestos Exposures during Reprocessing of Automobile Brakes and Clutches

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Asbestos exposures of workers in three small factories reprocessing automobile brakes and clutches in Japan were investigated. Airborne asbestos was collected on a membrane filter using an air sampler. From 1982 to 1989, asbestos counting was performed on 295 samples (198 personal and 97 stationary), using phase contrast microscopy. Only chrysotile asbestos was detected. Workers who reprocessed automobile brakes and clutches were exposed to asbestos concentrations of 0.025–76.4 fibers/cm^3. Geometric mean asbestos concentrations during attaching linings to brake shoes and attaching facings to clutch disks were 0.859 fibers/cm^3 and 0.780 fibers/cm^3, respectively. Concentrations during stripping worn brake linings and clutch facings were 0.484 fibers/cm^3 and 0.382 fibers/cm^3, respectively. Machine grinding and leveling of new brake-lining surfaces represent potential sources of heavy asbestos exposures, unless enclosures and local ventilation are efficient. *Key words*: asbestos; automobile brake and clutch reprocessing; small-scale industry.

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In Japan, during the early 1980s , at least 400 companies were involved in the reprocessing of automobile brakes and clutches.[1] In 1982, of the 400 companies, 190 that employed 1,611 workers were organized to form a society of reprocessing companies. Companies employing fewer than ten workers comprised 75% of this society. Of the member companies, 33% had been founded between 1955 and 1964 and 59%, after 1965.[1] The number of member companies increased with the widespread use of automobiles in Japan. Meanwhile, the number of reprocessed automobile parts increased with every passing year. Brakes and clutches, in particular, were the principal reprocessed parts. In 1982,[2] approximately 17,500 tons of asbestos were used for manufacturing brake linings, clutch facings, and disk pads. The chrysotile contents of these brake linings and clutch facings usually ranged from 40% to 60%.[3,4]

Although there are numerous reports of airborne asbestos concentrations in automobile repair and service shops,[5–11] there are very few reports of asbestos exposure levels in factories that reprocess brakes and clutches.[11]

Langer and McCaughey[12] reported the case of a brake-repair worker who contracted mesothelioma. Levin et al.[13] presented the case of a clutch refabricator who had asbestosis and lung cancer, and the chrysotile concentration in lung tissue of this patient exceeded the reference values by a large margin. Dahlqvist et al.[14] reported that the degree of airway closure was positively correlated with an increased cumulative exposure to asbestos, even after controlling for age, height, smoking, and exposure to diesel exhaust. Lemen[15] stated that the alleged "controlled" use of asbestos-containing brakes posed a health risk to workers, users, and their families. Thus, workers reprocessing automobile brakes and clutches are at risk for asbestos-related health disorders.

From 1982 to 1989, we determined the airborne asbestos concentrations in three small-scale factories that reprocessed automobile brakes and clutches. As mentioned previously, available information about asbestos exposures in the automobile clutch- and brake-reprocessing industry is very limited. The results of our study, which was conducted in the 1980s, can provide valuable information for the risk assessment of asbestos-related diseases in this industry.

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TABLE 1 Survey Dates and Numbers of Samples

Dates	Factory	No. Samples Personal	Stationary
1982			
July 16	A	5	5
July 27	A	6	6
October 12	A	8	0
1983			
June 11	A	1	0
June 18	B	6	5
June 22	A	2	6
August 24	C	17	22
1984			
July 9	A	31	9
July 15	B	30	10
July 18	C	27	10
1985			
July 16	A	21	6
July 17	B	20	8
July 18	C	24	0
1989, August 11	B	0	10
TOTAL		198	97

MATERIALS AND METHODS

Materials

Between 1982 and 1989, sampling was repeatedly performed in three factories in Nagoya that reprocessed automobile brakes and clutches. Table 1 shows the number of samples used for measurement on each day. A total of 295 (198 personal and 97 stationary) samples was obtained.

Personal Sampling

Personal samples were collected from the breathing zone of each worker either throughout a single operation or throughout two different operations. The samples were collected on membrane filters (Millipore type AA; 0.8 μm pore size; 47 mm diameter), using a personal sampler (Roken type, Sibata Scientific Technology). Personal samplers were attached to workers' lapels. The sampling flow rate was 1.0 L/min, and, depending on the duration of the operation, sampling times ranging from 4 to 135 min were set. Subjects were selected from among workers reprocessing automobile brakes and clutches.

Stationary Sampling

Stationary samples were taken according to the Working Environment Measurement Standards of Japan.[16] More than five fixed sampling points were set up in a given unit work area. The samples were collected on membrane filters (Millipore type AA; 0.8 μm pore size; 47 mm diameter) using an open-face filter holder (Model 3400, Sartorius). Sampling was performed at a flow rate of 10 L/min using a suction pump (Model IP-30L, Sibata Scientific Technology); sampling times ranged from 15 to 60 minutes. The samples were obtained from a height of 0.5–1.5 m above the workplace floor. There were five unit work areas, one in factory A and two each in factories B and C.

Counting Method

Asbestos particles were counted using a phase-contrast microscope (BHB-331, Olympus), in accordance with the standardized method developed by the Japan Association of Industrial Health.[17] To elaborate, a small portion of each filter was cut and mounted on a glass slide with a medium consisting of dimethyl phthalate and diethyl oxalate (1:1) and then covered with a cover glass. Up to more than 100 fibers or 20 areas within the given graticule field, at a magnification of 400×, were counted. Only the fibers that met the following criteria were counted: length greater than 5 μm, diameter less than 3 μm, and aspect ratio greater than 3:1.

The detection limit for personal sampling when collecting 60 L of air and counting 20 areas within the given graticule field was 0.006 fibers/cm^3, and that for stationary sampling when collecting 600 L of air and counting 20 areas within the given graticule field was 0.0006 fibers/cm^3.

Identification of Asbestos

A transmission electron microscope (H-800, HITACHI) equipped with an energy-dispersive X-ray analyzer (EDXA, KEVEX-7000) was used for identification of asbestos during the analysis of some samples. Asbestos was morphologically (e.g., the hollow-tube structure of chrysotile) identified with the help of EDXA.

Mean Asbestos Concentrations

The mean asbestos concentration of each operation was obtained in the following manner:

1. Where more than two samples were obtained from an operation on any day of measurement, the mean asbestos concentration of that operation in the factory on that particular day was calculated as a geometric mean, because airborne asbestos concentrations distribute log-normally.
2. The mean asbestos concentration of an operation was obtained by calculating the geometric mean of the obtained geometric mean asbestos concentrations on the day of measurement.

Calculation of Evaluation Values and Control Class Classification

The values of asbestos concentration measured by stationary sampler at a unit work area were processed fol-

TABLE 2 Profiles of Surveyed Factories as of 1983

Factory	Floor Area (m^2)	No. of Workers*	Average Monthly Reprocessing Amounts (Pieces)		Working Hours (per Day)	No. Local Exhaust Ventilators in Factory
			Brake	Clutch		
A	300	20 (10)	19,600	1,700	7.3	8
B	362	20 (10)	27,500	300	7.5	7
C	452	19 (7)	12,500	4,000	7.8	26

*Number in parentheses is number of workers handling friction materials directly.

lowing the Working Environment Evaluation Standard[18] of the Japanese government. After calculating geometric mean (GM) and geometric standard deviation (GSD) of measured concentrations, the first evaluation value (E1) and the second evaluation value (E2) were calculated by the following formulas.

$$\text{LogE1} = \log\text{GM} + 1.645 \times \sqrt{(\log^2\text{GSD} + 0.084)}$$

$$\text{LogE2} = \log\text{GM} + 1.151 \times (\log^2\text{GSD} + 0.084)$$

If we measure airborne asbestos concentration by stationary sampler at every possible point and time during working hours in a unit work area, we will get an infinite number of concentration values. The E1 is a statistically estimated concentration corresponding to 5 percentile points from the highest value among them. The E2 is the estimated arithmetic mean of infinite asbestos concentration values.

The next step is sorting unit work areas into three control classes based on comparisons among E1, E2, and an administrative control level (ACL) (explained in the Discussion section). The sorting criteria for control classes 1, 2, and 3 are E1 < ACL, E2 = < ACL = < E1, and ACL < E2, respectively.

The measures required for control classes 1, 2, and 3 are: 1) maintaining the present good condition; 2) an effort to reduce exposure further; and 3) immediate action to reduce exposure, respectively.[18]

Reports to Employers

The result of each assessment of the working environment was reported to the respective employer. The reports consisted of the determined airborne asbestos concentrations and recommendations for measures to reduce asbestos exposures of workers.

RESULTS

Profiles of Factories

The three surveyed factories had begun to function around 1955 and were comparatively large companies in the brake- and clutch-reprocessing industry. Factories A and B were located in areas having both small-scale factories and private homes. However, factory C was located in a residential area. Factory A was a one-story structure and factories B and C were two-storied structures. Table 2 shows the characteristics of each factory. In 1983, 27 of the 57 workers directly handled automotive friction materials, and the remaining workers did not. Ages and employment periods were available for 52 of these 57 workers. The mean ages (range) of the male and female workers were 42 (19–71) years and 44 (34–54) years, respectively. The mean employment periods (range) of the male and female workers were 15 (1–34) years and 8 (0.5–28) years, respectively. The work processes and the amounts of time spent on various operations in the three factories were similar. The work processes and operations remained unchanged through the 1980s, and the work was carried out on a regular basis. The labels of the friction materials specified the asbestos content (50%) and contained a hazard warning. The weights of the brake linings and the clutch facings that were mainly used were 0.23 kg/piece and 0.22 kg/piece, respectively. It was estimated that, every month, 4.8 tons of friction materials were utilized at factory A, 6.3 tons at factory B, and 3.7 tons at factory C.

Asbestos-free substitutes were not used at that time. In the present study, working-environment measurements were obtained only in the summer. On the days of measurement, the doors and windows of factories A and B were kept open. However, the doors and windows of factory C were kept closed in some workplaces throughout the day because of air-conditioning. Only a few workers used personal respiratory protective equipment.

Processes

Figure 1 illustrates the sequence of operations during the reprocessing of automobile brakes and clutches. The main process consisted of four steps:

Step 1. Stripping used brakes and clutches to pieces (1 and 2 in Figure 1). Used drum brakes are heated in a furnace to burn off the glue that bonds the brake linings and the shoes. The iron shoes are stripped off the worn asbestos linings (Figure 2A). The rivets binding the clutch facing and the disk are loosened using a drilling machine (Figure 2B). The iron disks are then stripped off the worn clutch facings.

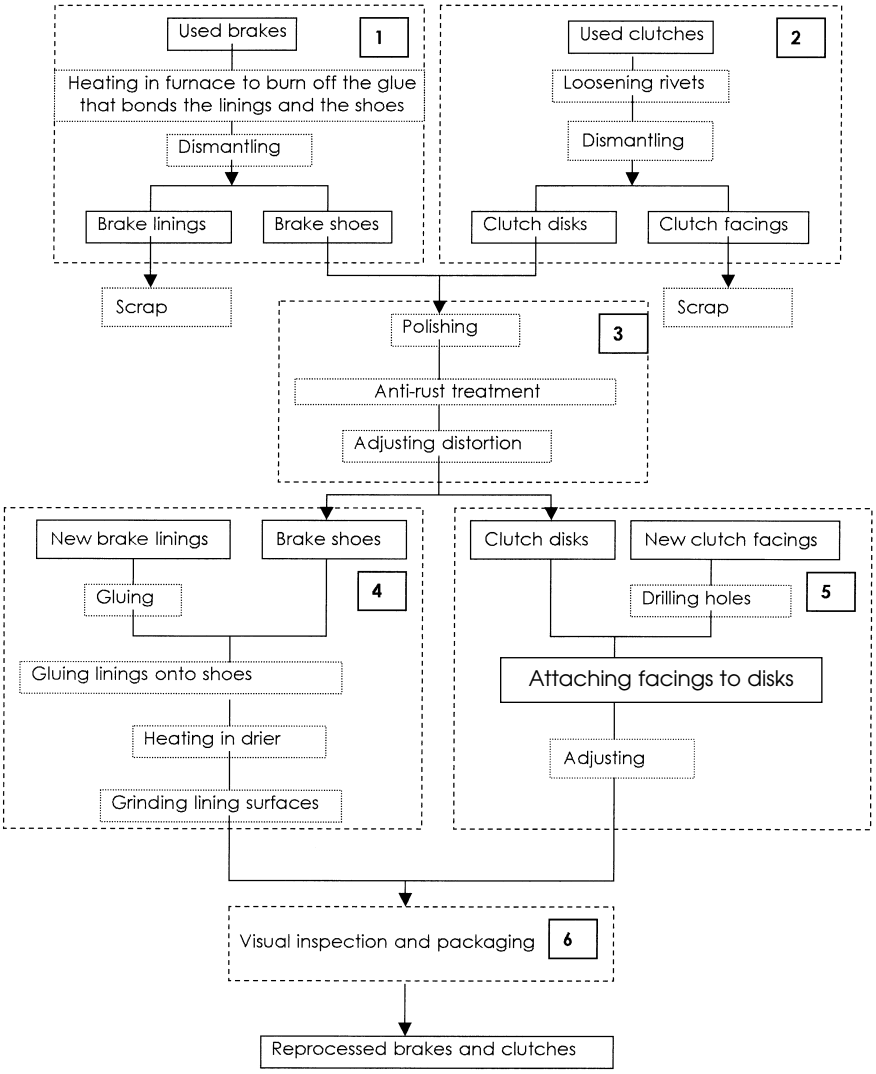

Figure 1—Sequence of operations in the reprocessing of brakes and clutches. Boxed numbers indicate process numbers in Table 3.

Step 2. Cleaning the brake shoes and clutch disks (3 in Figure 1). The recovered brake shoes and clutch disks are polished by shot blasting or using a hand brush. After polishing, the shoes and disks are painted to impart anti-rust properties to them, and adjusted if any distortion is observed.

Step 3. Reassembling brakes and clutches (4 and 5 in Figure 1). New linings are glued onto the brake shoes. The reassembled brakes are cured in an oven at temperatures of 200–300° C. The new brake-lining surfaces are ground with a grindstone (Figure 2C) or band grinders (Figure 2D). Holes are drilled into the new facings (Figure 2E), which are subsequently riveted to the clutch disks.

Step 4. Visual check and packing (6 in Figure 1). The reprocessed brakes and clutches are visually inspected and then packaged.

Asbestos Levels in Personal Samples

Table 3 presents the asbestos concentrations in the personal samples, which are classified by operation. Asbestos was detected in all the air samples, and chrysotile was the only fiber type detected. The highest geometric mean concentration of asbestos (44.2 fibers/cm^3) was found when grinding brake linings using a band grinder, even though a local exhaust ventilator was in use. This operation was performed in factory A only. The geometric mean asbestos concentrations during the attaching of linings to brake shoes and the attaching of facings to clutch disks were 0.859 fibers/cm^3 and 0.780 fibers/cm^3, respectively. The heaviest exposure observed during the attaching of brake linings to shoes (4.80 fibers/cm^3) was due to drilling the lining. The heaviest exposure observed during the attaching of clutch facings (3.15 fibers/cm^3) to clutch disks was due to the riveting on of a clutch facing. In 2000, the Japan Society for Occupational Health (JSOH) recommended 0.15 fibers/cm^3 as a reference value corresponding to an individual excess lifetime risk of cancer among 1,000 workers (relevant description is given in the Discussion section).[19] The geometric mean asbestos concentration exceeded 0.15 fibers/cm^3 in the following operations: grinding

Figure 2—Operations comprising reprocessing of brakes and clutches.

A. Stripping worn linings from brake shoes on a table after heating used brakes in a furnace.

B. Loosening of the rivets in a used clutch using a drilling machine.

C. Grinding the lining of a reassembled brake with a grindstone.

D. Grinding the lining of reassembled brake using a band grinder.

E. Drilling holes in a new clutch facing for the riveting.

brake linings with a grindstone, drilling holes into clutch facings, gluing linings onto brake shoes, and stripping worn brake linings and clutch facings. The geometric mean asbestos concentrations were less than 0.15 fibers/cm^3 in the remaining operations.

During the grinding of the linings with a grindstone, the geometric mean asbestos concentration in factory C was 0.287 fibers/cm^3, compared with 0.867 fibers/cm^3 in factory A and 0.782 fibers/cm^3 in factory B.

The differences in asbestos concentrations between factories were large during operations such as drilling holes into clutch facings and attaching brake linings to shoes and clutch facings to disks. When the asbestos concentrations during the same operation were compared among the three factories, factory C always had the lowest geometric mean asbestos concentrations, except when worn brake linings were stripped. A majority of the grinders and drills and a shot-blasting machine were equipped with local exhaust ventilators in factory C; in contrast, factories A and B had very few such local exhaust ventilators. Only factory C had a local exhaust ventilation duct in the workplace in which worn brake linings were stripped; however, the size and the location of the duct were not appropriate. The workplace in factory C was frequently cleaned using a vacuum cleaner. Accumulation of deposited

TABLE 3 Mean Airborne Asbestos Concentrations in Personal Samples Corresponding to the Various Operations

Process (No.)* and Operation	Factory A					Factory B				
	Sampling Duration (Min)		Asbestos Concentration (Fibers/cm³)†			Sampling Duration (Min)		Asbestos Concentration (Fibers/cm³)†		
	Mean	(Range)	No.†	Geometric Mean	(Range)	Mean	(Range)	No.†	Geometric Mean	(Range)
Stripping worn brake linings (1)	54	(10–70)	3	0.350	(0.11–0.80)	47	(5–60)	2	0.695	(0.220–1.17)
Stripping worn clutch facings (2)		—	0		—	59	(56–70)	1	0.524	—
Cleaning (3)										
Adjusting and polishing		—	0		—	49	(36–60)	2	0.098	(0.08–0.116)
Painting	62	(60–63)	2	0.100	(0.10–0.10)	62	(62–62)	1	0.144	—
Reassembling brakes (4)										
Gluing linings to brake shoes	64	(60–68)	1	0.135	—	55	(40–61)	2	0.157	(0.149–0.165)
Attaching linings to shoes	30	(5–76)	3	1.739	(0.12–4.80)	50	(49–50)	1	0.234	—
Grinding linings with a grindstone	55	(15–135)	6	0.867	(0.22–2.42)	46	(12–60)	3	0.782	(0.120–1.39)
Grinding linings with a band grinder	10	(10–10)	2	44.2	(12.0–76.4)		—	0		—
Reassembling clutches (5)										
Drilling holes into clutch facings	42	(10–62)	4	0.793	(0.155–2.40)	30	(15–60)	2	0.383	(0.12–0.646)
Attaching facings to disks	55	(15–72)	3	0.397	(0.155–0.64)	58	(49–67)	2	1.669	(0.187–3.15)
Visual checking and packing (6)	22	—	1	0.13	—	48	(15–67)	3	0.129	(0.095–0.153)
Combination	71	(24–135)	12	0.159	(0.027–0.33)	55	(35–63)	10	0.190	(0.09–0.32)

*The number in parentheses indicates the process number in Figure 1.
†Number of days of measurement of airborne asbestos concentrations.
‡Arithmetic mean of the geometric mean for each measurement day (when more than two samples were obtained for an operation on a day of measurement, then the mean asbestos concentration of the operation on that day was expressed as the geometric mean for each factory).

dust was observed on all the flat surfaces of the machines as well as on the floors of factories A and B.

Asbestos Exposure Levels in Stationary Samples

Table 4 summarizes the asbestos concentrations in the one unit work area in factory A and two each in factories B and C. Measurements were repeatedly performed in the five unit work areas from 1982 to 1989. Of 15 unit work areas, 14 were classified as Control Class 3, that is, the mean concentration of airborne chrysotile in the unit work area exceeded the administrative control level (0.15 fibers/cm^3), and measures were needed to improve the working environment.

The operations nearest to the sampling locations (0.3–5 m) were the basis of classification of the stationary samples, and the highest geometric mean concentration of asbestos (1.253 fibers/cm^3) was obtained during the operation of attaching clutch facings to disks. The geometric mean concentration exceeded the occupational exposure limit (0.15 fibers/cm^3) in the following operations: drilling holes in clutch facings, grinding brake linings with a grindstone, stripping worn brake linings and clutch facings, attaching brake linings to shoes, visual inspection and packaging, and gluing linings to brake shoes. The asbestos concentration in a locker room in factory B was 1.72 fibers/cm^3. The locker room was situated close to the workplace where brakes were reassembled.

Attaching brake linings to shoes in factory A produced asbestos concentrations of 0.26 fibers/cm^3, 0.24 fibers/cm^3, and 0.08 fibers/cm^3 1 m, 2 m, and 3 m away from the operator, respectively. In factory A, grinding brake linings with a grindstone produced asbestos concentrations at distances of 1 m and 2 m from the operator of 3.5 fibers/cm^3 and 1.2 fibers/cm^3, respectively. Thus, airborne asbestos concentrations deceased as the distance from the operator increased.

TABLE 3 (continued)

Process (No.)* and Operation	Factory C					Factory D				
	Sampling Duration (Min)		Asbestos Concentration (Fibers/cm^3)†			Sampling Duration (Min)		Asbestos Concentration (Fibers/cm^3)†		
	Mean	(Range)	No.†	Geometric Mean	(Range)	Mean	(Range)	No.†	Geometric Mean	(Range)
Stripping worn brake linings (1)	41	(4–60)	3	0.477	(0.120–1.11)	47	(4–70)	8	0.467	(0.11–1.17)
Stripping worn clutch facings (2)	60	—	1	0.24	—	59	(57–90)	2	0.355	(0.24–0.524)
Cleaning (3)										
Adjusting and polishing	60	(60–61)	2	0.047	(0.033–0.06)	55	(36–61)	4	0.068	(0.033–0.116)
Painting		—	0		—	62	(60–63)	3	0.113	(0.10–0.144)
Reassembling brakes (4)										
Gluing linings to brake shoes		—	0		—	58	(40–68)	3	0.149	(0.135–0.165)
Attaching linings to shoes	32	(9–62)	3	0.188	(0.07–0.334)	34	(5–76)	7	0.503	(0.07–4.80)
Grinding linings with a grindstone	37	(9–61)	2	0.287	(0.090–0.483)	46	(9–135)	11	0.689	(0.090–2.42)
Grinding linings with a band grinder		—	0		—	10	(10–10)	2	44.2	(12.0–76.4)
Reassembling clutches (5)										
Drilling holes into clutch facings	65	(59–80)	1	0.065	—	46	(10–80)	7	0.451	(0.12–2.40)
Attaching facings to disks	52	(43–60)	1	0.152	—	55	(15–72)	6	0.546	(0.152–3.15)
Visual checking and packing (6)	60	—	1	0.07	—	46	(15–67)	5	0.114	(0.07–0.153)
Combination	63	(60–85)	7	0.142	(0.05–0.21)	63	(24–135)	29	0.165	(0.027–0.33)

LONG-TERM TRENDS

Figure 3 shows the trends observed from 1982 to 1985 in the geometric mean asbestos concentrations corresponding to the various operations in the personal samples from factory A. Asbestos exposure levels had a tendency to decrease. The geometric mean of the asbestos concentrations in the unit work area in factory A also decreased. Figure 4 showed the trends observed from 1983 to 1985 with regard to the geometric mean asbestos concentrations corresponding to the various operations in the personal samples from factories B and C. Although the asbestos exposure levels in factory C decreased with every passing year, the asbestos exposure levels fluctuated in factory B. In the personal samples, the asbestos exposure levels were expressed as the geometric mean asbestos concentrations corresponding to the operation, and a large variation in the asbestos concentrations was observed among the operations.

Relationship between Personal and Area Concentrations

Figure 5 shows the relationship between the geometric mean airborne asbestos concentrations determined with personal and stationary samplers at only 13 unit work areas because there were no personal samples obtained in the other two unit work areas. The personal sample data were reclassified into groups according to the unit work area and the day of measurement. Although large discrepancies were observed with regard to the mean asbestos concentrations of the personal and stationary samples at some unit work areas, the mean asbestos concentrations of the personal samples significantly increased along with those of the stationary samples at the unit work areas ($p < 0.01$). The mean asbestos concentrations of the personal samples tended to be higher than those of the stationary samples.

DISCUSSION

Comparison with Reference Values and Administrative Control Levels

In Japan, there have been two kinds of occupational health standards for airborne asbestos. One is the occupational exposure limit (OEL) recommended by the Japan Society for Occupational Health (JSOH). This is

TABLE 4 Airborne Asbestos Concentrations in Individual Unit Work Area

Unit Work Area No.	Factory	Story	Date	Asbestos Concentration (fibers/cm^3) Geometric Mean (Geometric Standard Deviation)	First Evaluation Value	Second Evaluation Value	Control Class*
1	A	First	7/16/82	1.96 (1.66)	5.14	3.85	3
			7/27/82	0.483 (1.89)	1.49	1.06	3
			6/22/83	0.356 (2.07)	1.29	0.877	3
			7/9/84	0.189 (1.70)	0.510	0.379	3
			7/16/85	0.178 (3.43)	1.43	0.763	3
2	B	First	6/18/83	0.598 (3.34)	4.60	2.49	3
			7/15/84	0.125 (1.69)	0.334	0.249	3
			7/17/85	1.17 (2.55)	5.87	3.62	3
			8/11/89	0.554 (2.23)	2.25	1.48	3
3	B	Second	7/15/84	0.144 (1.22)	0.257	0.216	3
			8/11/89	0.132 (1.49)	0.297	0.233	3
4	C	First	8/24/83	0.155 (1.43)	0.329	0.262	3
			7/18/84	0.045 (2.55)	0.227	0.140	2
5	C	Second	8/24/83	0.174 (1.39)	0.360	0.289	3
			7/18/84	0.145 (2.61)	0.751	0.458	3

*Comparison with Administrative Control Level amended in 2004 (0.15fibers/cm^3).

defined as the reference value for the mean exposure concentration at or below which adverse health effects caused by the substance do not appear in most workers working for eight hours a day, 40 hours a week under a moderate workload.[19] The OEL promulgated by academia is not legally enforceable. The JSOH has revised its OEL for asbestos three times. It was 2 mg/m^3 until 1973.[20] In 1974, it was amended to 1) crocidolite 0.2 fibers/cm^3 and 2) other types of asbestos 2 fibers/cm^3, and 10 fibers/cm^3 as ceiling limit (ceiling limit is an average concentration for 15 minutes which should not be exceeded at any time during a workday).[21] In 1996, it became crocidolite 0.2 fibers/cm^3 and chrysotile 2 fibers/cm^3, and remaining types of asbestos were noted as under consideration.[22] In 2000 JSOH abandoned the conventional OEL for asbestos and changed it to reference values corresponding to an individual excess lifetime risk of cancer based on an average-relative-risk model. Regarding chrysotile, JSOH recommends 0.15 fibers/cm^3 and 0.015 fibers/cm^3 as reference values corresponding to the aforementioned risk among 1,000 and 10,000 workers, respectively.[19,23]

The other standard for asbestos is the administrative control level.[18] The Japanese government has devel-

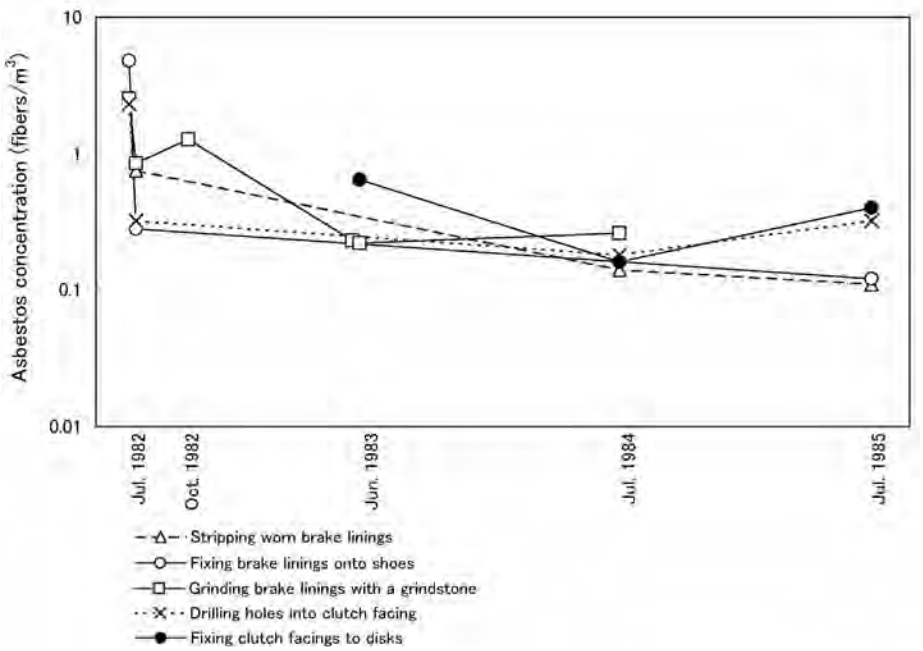

Figure 3—Trends of geometric mean asbestos concentrations from 1982 to 1985 in personal samples classified by operations in factory A.

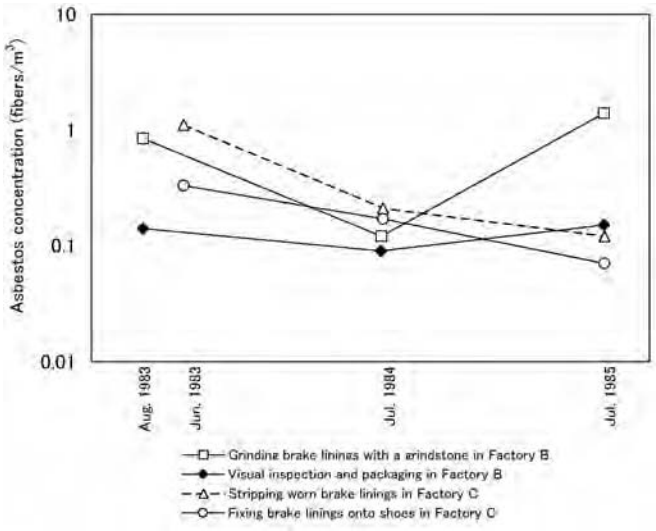

Figure 4—Trends of geometric mean asbestos concentrations from 1983 to 1985 in personal samples classified by operation in factories B and C.

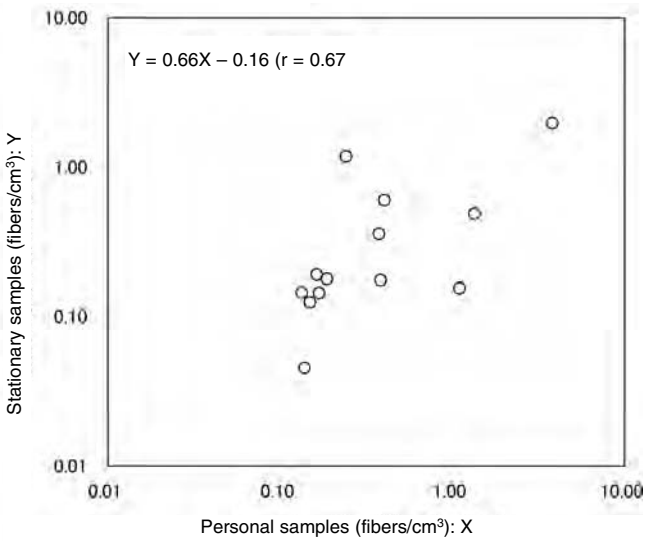

Figure 5—Relationship between geometric mean asbestos concentrations of personal and stationary samples at 13 unit work areas.

oped a unique working-environment control system. The administrative control level is an indicator to assess whether hazardous substances in a workplace are controlled well or the workplace requires engineering control measures.[24] In 1984, the government issued the administrative control levels as a non-enforceable standard by an administrative notification; later it was changed to an enforceable standard by the Working Environment Evaluation Standard[18] in1988. The administrative control level for asbestos was 2 fibers/cm^3. The administrative control level was lowered to 0.15 fibers/cm^3 in 2004.[25] Therefore, the personal exposure levels are research data and the airborne levels in the unit work areas are government-compliance data.

The geometric mean asbestos concentrations in the personal samples exceeded reference value (0.15 fibers/cm^3) during four processes, namely, stripping worn brake linings, stripping worn clutch facings, reassembling brakes, and reassembling clutches. In the personal samples, the geometric mean asbestos concentration estimated when grinding linings with a band grinder (44.2 fibers/cm^3) was the highest among all the operations. The machine grinding of brake linings was the most potent source of heavy asbestos exposure. In this study, regarding the personal sampling, we focused on measuring the asbestos exposure concentrations by operations. We did not conduct a time study to elaborate the time that a worker spent for each operation within a day. Therefore, the time-weighted average concentrations of asbestos exposure are unavailable.

There were 15 unit work areas in this study because the measurements were performed repeatedly in five unit work areas of the working environment. The second evaluation values exceeded the administrative control limit (0.15 fibers/cm^3)[25] in 14 of the 15 unit work areas. This means that the working environments in those unit work area were unacceptable condition. In those workplaces, the following measures were recommended to reduce asbestos exposures: industrial hygiene engineering measures, better housekeeping practices, and personal protective equipment.

Comparison with Previous Reports

There have been seven previous reports of airborne asbestos concentrations in automobile repair and service industries.[5–11] To the best of our knowledge, the only report focusing on factories reprocessing automobile brakes and clutches was from a study of airborne asbestos exposures in brake-bonding workshops, where the used brakes that were collected from brake service stations in Australia were employed.[11] The authors reported that the geometric means of the asbestos concentrations in brake-bonding workshops were less than 0.17 fibers/cm^3. These values are much lower than those estimated in this study. They described that the low exposure levels could be attributed to the recent use of wet methods, which have replaced the traditional dry methods.

Table 5 summarizes the airborne asbestos concentrations during automobile brake- and clutch-reprocessing work and brake maintenance or repairs described in the literature. Boillat and Lob[5] have reported asbestos concentrations measured during the drilling and grinding of brake linings; they found values ranging from 0.3 to 29.2 fibers/cm^3. Rohl et al.[6] reported that the average asbestos concentration was 37.3 fibers/cm^3 in the vicinity of the operator during the beveling of truck brake shoes on a grinding machine. The airborne asbestos concentration 9 m away from this operation was 0.3 fibers/cm^3. Lorimer et

TABLE 5 Airbone Asbestos Exposure Levels during Brake Maintenance or Repair Work Reported in the Literature

Product and Operation*¶	No. of Samples	Sampling Duration (Min)	Asbestos Concentration (Fibers/m^3) Mean‡	Asbestos Concentration (Fibers/m^3) Range	Year of Publication	Reference
Brakes						
Drilling holes	1	—	0.6	—	1983	5
Grinding linings	7	—	—	0.9–29.2		
Renewing used linings by grinding (3–5 ft away)	10	—	3.8	1.7–7.0	1976	7
Renewing used linings by grinding (10 ft away)	2	—	1.5	1.2–1.7		
Renewing used linings by grinding (25 ft away)	2	—	0.8	0.6–1.0		
Beveling new linings (3–5 ft away)	5	—	37.3	23.7–72.0		
Beveling new linings (8 ft away)	1	—	0.6	—		
Beveling new linings (12 ft away)	2	—	0.4	0.3–0.5		
Beveling new linings (30 ft away)	1	—	0.3	—		
Punching rivets into brake linings (3–5 ft away)	2	—	1.5	0.9–2.0		
Light grindings of new linings before installation	2	—	3.7	2.7–4.7		
Light grinding of new lining before installation	1	—	4.8	—	1976	8
Grinding new linings before installation	1	—	2.7			
Renewing used linings by grinding	12	2–10	3.8	1.7–7.0		
Beveling new linings	5	2–10	37.5	23.7–72.0		
Brake pad machining	3	10	0.55	0.04–0.83	1986	9
Riveting off and on (truck)	7	<60	0.10	—	1986	10
Grinding by hand (passager)	7	<60	0.12	—		
Machine grinding (passager)	5	<60	0.06	—		
Loosening rivets from brake linings	12	5–29	0.3	<0.1–1.6	1987	11
Punching rivets into brake linings	28	3–60	0.7	0.1–3.5		
Grinding brake linings with machine, exhaust ventilation not in use	5	4–27	56	0.3–125		
Grinding brake linings with machine, exhaust ventilation in use	30	4–33	1.5	0.1–5.9		
Bevelling edges of brake linings with file	7	2–5	0.4	0.1–0.9		
Assembling of brakes	7	6–41	0.2	<0.1–0.4		
Grinding of brake drums	6	3–26	0.2	0.1–0.3		
Reprocessing brakes†	17	77–135	<0.05§	<0.05–<0.07	1999	12
Clutches, reprocessing†	7	125	<0.05§	<0.05–0.04	1999	12

*Personal samples; †stationary samples; ‡arithmetic mean; §geometric mean.
¶The opening, brushing, and cleaning of brakes and clutches were excluded.

al.[7] reported that asbestos concentrations during the grinding of a new lining, before installation, were 2.7 and 4.8 fibers/cm^3. Cheng et al.[8] reported that asbestos concentrations during brake-pad machining ranged from 0.04 to 0.83 fibers/cm^3, with a mean of 0.55 fibers/cm^3. Rodelsperger et al.[9] reported that the mean asbestos concentration during the machine grinding of brake linings was 0.06 fibers/cm^3. During the machine grinding of brake linings, Kauppinen et al.[10] found a mean asbestos concentration of 56 fibers/cm^3 in the absence of exhaust ventilation and a mean concentration of 1.5 fibers/cm^3 when exhaust ventilation was present; they also reported concentrations of up to 125 fibers/cm^3 during the grinding of brake linings with a machine. There are large differences among the airborne asbestos concentrations estimated in similar operations in the previous reports. The low asbestos levels could be attributed to better control of the working environment. Our results and previous reports demonstrate that machine grinding and beveling of the new brake lining surface can become the sources of heavy asbestos exposure, unless the enclosure and local ventilation are efficient.

Asbestos Exposures in Individual Factories

The operations in the individual factories remained unchanged in the 1980s; however, the asbestos exposure levels then decreased in factories A and C, but not in factory B. The geometric mean asbestos concentrations of the personal samples tended to be higher than those of the stationary samples at unit work areas. This might be due to the distances between asbestos-dust emission sources and sampling points. The personal

sampling points were closer to the emission sources than were the stationary sampling points. The asbestos concentrations in factory C were lower than those in the others; this could have been due to the presence of a larger number of local exhaust ventilators and frequent cleaning of the workshop.

Limitations and Significance of This Study

This study has a couple of limitations. First, it may not be representative of all workers exposed to asbestos in factories across Japan that reprocess automobile brakes and clutches, because the factories in this study were not selected randomly and the number of the study subjects was small. Second, this study was conducted during the summer, and it is known that the asbestos concentrations in such factories may be higher during the winter because of poor natural ventilation, which occurs when windows and doors are kept closed to maintain warm temperatures in the workplace. Despite these limitations, since asbestos exposures in the automobile brake- and clutch-reprocessing industry have not been sufficiently elucidated to date, the information presented by the present study could be useful for retrospective exposure assessments in this industry.

In Japan, automobile brake pads and linings and clutch facings containing asbestos were banned in October 2004. In addition, products containing crocidolite or amosite were legally prohibited from import, manufacture, supply, and use in 1995.[26] The government also banned products containing more than 1% chrysotile, such as automobile brake pads and linings and clutch facings, except for specified products for which substitutes were unavailable, in October 2004.[27] Asbestos-containing automobile friction materials continue to be manufactured and used in industrializing countries[28]; however, these countries are phasing out the use of asbestos.[29] If used brakes and clutches are reprocessed in industrializing countries, asbestos exposures should be monitored and the measures necessary to reduce such exposures taken.

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