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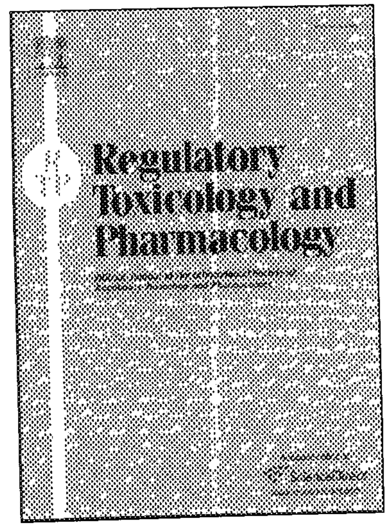

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Evaluation of Asbestos Exposure within the Automotive Repair Industry: A Study Involving Removal of Asbestos-Containing Body Sealants and Drive Clutch Replacement

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ABSTRACT

Two independent assessments were performed of airborne asbestos concentrations generated during automotive repair work on vintage vehicles . The first involved removal of asbestos-containing seam sealant, and the second involved servicing of a drive clutch. Despite the relatively high concentrations (5.6 to 28%) of chrysotile fibers detected within bulk samples of seam sealant, the average asbestos concentration for personal breathing zone (PBZ) samples during seam sealant removal was 0.006 fibers/cubic centimeter of air (f/cc). Many other air samples contained asbestos at or below the analytical limit of detection (LOD). Pneumatic chiseling of the sealant material during removal resulted in 69% of area air samples containing asbestos. Use of this impact tool liberated more asbestos than hand scraping. Asbestos fibers were only detected in air samples collected during the installation of a replacement clutch. The highest asbestos corrected airborne fiber concentration observed during clutch installation was 0.0028 f/cc. This value is approximately 100 times lower than Occupational Safety and Health Administration's (OSHA) permissible exposure limit (PEL) of 0.1 f/cc. The airborne asbestos concentrations observed during the servicing of vintage vehicles with asbestos-containing seam sealant and clutches are comparable to levels reported for repair work involving brake components and gaskets.

Keywords: Asbestos, Chrysotile, Exposure, Automotive, Mechanics, Clutches, Seam Sealant, Asbestos-Containing Materials

1. INTRODUCTION

The presence of asbestos in automobile brakes, gaskets, clutches, and some undercoating and its potential to be liberated during the servicing of vehicles has given rise to many concerns of increased risk of asbestos-associated diseases among automotive mechanics (Huncharek, 1990, Lemen, 2004). It is estimated (Sheehy et al., 1989) that approximately 900,000 mechanics and garage workers in the U.S. have been historically exposed to asbestos through the handling and servicing of asbestos containing materials (ACMs). However, related epidemiological studies do not show an increased risk of asbestosis, lung cancer or mesothelioma as asbestos-related diseases within these occupational cohorts (McDonald and McDonald, 1980; Wong, 1992, 1993, 2001, 2006; Spirtas et al. 1994; Teschke et al. 1997; Agudo et al. 2000; Goodman et al., 2004; Hessel et al., 2004; Laden et al., 2004; Welch et al., 2005; Kelsh et al., 2007).

Available exposure assessments and simulation studies of asbestos levels predominantly focus on replacement of chrysotile-containing brake parts in passenger cars and light-duty trucks. The results consistently demonstrate that fiber concentrations evaluated by phase contrast microscopy (PCM) are less than or equal to the current OSHA permissible exposure limit (PEL) of 0.1 fibers per cubic centimeter of air (f/cc) (OSHA, 1997; Yueng et al., 1999; Wier et al., 2001; Blake et al., 2003; Paustenbach et al., 2003, 2004; Finley et al., 2007). To characterize the asbestos concentrations generated during the replacement and installation of engine and exhaust gaskets, other studies were also initiated and the results demonstrated that workers performing these tasks may be exposed to asbestos, but at concentrations that are 10 to 100 times lower than current occupational exposure limits (OELs) (Yueng et al., 1999; Liukonen and Weir, 2005; Paustenbach, et al., 2005; Blake et al., 2006).

Although several studies address the issue of airborne chrysotile exposures during automotive brake and gasket replacements, there are only a limited number of reports involving the complete removal and subsequent replacement of automotive drive clutches. No additional studies were found which involved removal of chrysotile containing seam sealer or undercoating materials.

Regarding clutches, Lynch (1968) found no asbestos fibers in clutch wear debris following dynamometer testing. Jacko et al. (1973) quantified asbestos emissions from clutches during operation of manual transmission equipped automobiles. Hickish and Knight (1970) provided time weighted average (TWA) airborne fiber exposure data from clutch repair work, with concurrent brake cleaning on trucks. In 1999, Yeung et al. reported personal and area airborne fiber concentrations experienced during replacement of an asbestos-containing automotive clutch. Boelter et al. (2007) reported the airborne fiber and asbestos fiber concentrations associated with clutch repair work performed on a bulldozer and a track loader. Jiang et al. (2008) studied the asbestos fiber exposure potential occasioned during handling and packing of asbestos-containing clutch discs. Cohen and Van Orden (2008) reported the results of sampling performed during removal of asbestos-containing clutches from salvage (non-operational) passenger automobiles and trucks). These sampling results were combined with relevant task frequency and duration data to estimate the incremental 8-hr TWA exposures to mechanics who perform clutch repair work.

Seam sealant is a form of undercoating material applied to mechanical joints on unibody vehicles to prevent moisture intrusion and lessen road noise. Historically, automotive manufacturers commonly used an asphalt-based sealant that contained chryostile in concentrations ranging from 5 to 10% (Anderson and Farino, 1982).

Clutches have traditionally been grouped in with other asbestos-containing friction materials, such as brake linings and pads. These automotive components generally do not require extensive preparation to fit properly. The clutch discs usually can be directly inserted into the vehicle. For this reason, asbestos exposure during servicing of manual transmission clutches is not expected to result in significant release of asbestos.

The impact of ACMs associated with undercoating and clutches have not been assessed as thoroughly as other components, such as brakes and gaskets. In order to clarify the remaining exposures of mechanics, we have conducted exposure assessments to evaluate the potential for airborne asbestos exposure during removal of undercoating and changing of clutches while servicing vehicles. The specific purpose of this study was to assess asbestos exposure during the removal of asphalt-based seam sealant and during clutch replacement.

2.0 Methods

2.1 Seam Sealant Exposure Assessment

2.1.1. Test Location and Environmental Setting

This study was conducted in an operational automotive repair facility located in Ypsilanti, Michigan. The specific workspace used for this testing was a three bay garage.

Interior dimensions of the service space measured 60 feet (ft) by 80 ft with a 15 ft open ceiling. About 25% of the floor space within the service facility was allocated for the interior office that was located along the north wall. The outside pedestrian doors were located at the side of the office area on the north and east walls. The facility had an unpainted concrete floor, cinder block walls and painted metal deck roof with exposed steel structures. The test area was open to the remaining sections of the service facility. All external entrances, including three rollup doors providing access to the individual bays, were kept closed during each test session, but were opened between test sessions to facilitate removal of airborne particles generated in the previous test sessions. The automotive service facility had no ventilation system representing "the worst case" scenario for a mechanic engaged in the servicing of vehicles.

2.1.2. Test Vehicles

Two automobiles representing vehicle models manufactured in the 1960s through 1970s, with asbestos-containing seam sealant were selected for testing. Both vehicles were 1967 Ford Mustangs; one was a coupe, while the other was a fastback.

2.1.3. Mechanic's activities, equipment and tasks

Two methods of removing the asphalt-based undercoating material were used in this study. The first involved use of a hand scraper to manually remove the seam sealant from the wheel wells. The second method involved a handheld pneumatic chisel.

The professional mechanic that performed all work activities for this study was a former Ford Motor Company employee who specialized in repair and restoration of vintage vehicles. He serviced the test vehicles by using his standard work practices, in addition to specific workplace procedures required for the removal of seam sealant. To ensure an accurate assessment of the airborne asbestos levels, the test cars and test area were specially prepared. The automobiles were positioned on jack stands and the wheels were removed to provide access to the seam sealant material. To prevent possible liberation of asbestos fibers from the brake components, wheel hubs including the brake assemblies were covered with disposable plastic bags. Additionally, the facility was cleaned and inspected to prevent contribution of fibers from background.

Four wheel wells from the Mustang Coupe and three wheel wells from the Mustang Fastback were each subjected to two cycles of testing. In total, fourteen individual test sessions were conducted during removal of asbestos-containing seam sealant. In the first test cycle, the mechanic removed the mastic material with a hand scraper. Subsequently a pneumatic chisel was used in removing sealant from alternative sites of the same wheel well. Seam sealant was removed during 15-minute test intervals. During the first day of testing, the mechanic performed eight, 15-minute-duration removal exercises on the Mustang Coupe (two within each of four wheel wells), and one 15-minute-duration removal exercise on the Mustang Fastback. On the following day, five additional 15-minute-duration removal exercises were performed on the Mustang Fastback. All outside doors to the service facility were closed during each test session. Following each 15-minute sampling period, the bay and pedestrian doors were opened for approximately 30 minutes to facilitate "airing-out" of the automotive service facility. Additional activities were performed during the clean-up phase including removal of debris, wet-mopping of the floor and replacing/repositioning of the air samplers.

2.1.4. Air Sampling and Analysis

Personal breathing zone (PBZ) and area air samples were collected to estimate airborne fiber exposure levels that a mechanic and hypothetical bystanders would encounter during the work activities. This included five fixed location area air samples forming a 5 feet perimeter around the activity zone. One additional area air sample was located approximately 50 feet away from the activity zone and one personal sample was worn by the mechanic within his breathing zone. The equipment utilized for collecting samples consisted of line operated electric vacuum pumps that drew air at metered flow rates between 12 to 15 liters per minute (lpm) through cassettes containing mixed cellulose ester (MCE) filters with 0.8 micrometer (μm) pore size and 25 millimeter (mm) diameter. The individual pumps were checked with a primary calibration standard before and after each 15-minute sample collection period.

Samples were analyzed using phase contrast microscopy (PCM) and transmission electron microscopy (TEM). The PCM analysis followed the National Institute of Occupational Safety and Heath (NIOSH) Method 7400 Counting Method "A" (NIOSH, 1994a). Airborne fiber concentrations determined using PCM represent an index of possible asbestos fiber exposures. This is due to the inability of the PCM analytical method to distinguish between fibers of asbestos and non-asbestos origins. Also, the optical limitations of the PCM typically restrict its resolution capabilities to fibers wider than 0.25 μm. According to counting rules, particles not exhibiting at least a three to one (>3:1) length to width aspect ratio were excluded. This method is compliant with the requirements of the OSHA standards for asbestos air sampling. The PCM analysis of air samples includes all fibers meeting the dimensional criteria. Thus, the measured airborne fiber concentration may exceed the actual concentration of asbestos. In automotive repair shops, cellulose fibers, long thin metal fragments from power brushing activities and other fibers often appear in air samples. For this reason, an additional analysis of air samples was performed using TEM, following NIOSH Method 7402 (NIOSH, 1994b). This analytical method considers all fibers longer than 5 μm and wider than 0.25 μm, and allows development of an asbestos–to-total fiber ratio. This ratio is then multiplied by the airborne fiber concentration obtained from PCM analysis to yield an asbestos corrected airborne fiber concentration. This represents the asbestos fiber count applicable for comparison with an occupational exposure limit, for example with the OSHA PEL.

For the seam sealer testing, a direct asbestos fiber analysis was also conducted following NIOSH 7402 rules focusing on those asbestos fibers longer than 5 μm and wider than 0.25 μm.

2.1.5. Bulk Sampling and Analysis

Bulk samples of the seam sealant were collected from multiple locations of the test vehicles and placed into separate self-sealing plastic bags (Table 1). A total of 13 bulk samples of seam sealant were obtained and analyzed using TEM following the Chatfield Method (Chatfield, 1988) to determine type and concentrations of asbestos within each sample.

2.2 Clutch Exposure Assessment

2.2.1. Test Location and Environmental Setting

A metal building warehouse located in Benton, Kentucky with interior space that measured 40 ft by 32 ft with a 10 ft ceiling height was used as the site for clutch removal and replacement. The building was constructed in 1999 for the purpose of storing antique tractors and use as a metal work shop on limited occasions. No automotive maintenance activity was performed in this facility for approximately 5 years prior to testing. No ventilation or air conditioning system was installed in the building. An isolation barrier made of plastic sheets was placed over shelves along the entire West wall of the facility to prevent possible migration of dust. The storage facility had two sliding doors, each approximately 16 ft in length located at the North and South ends of the facility, and one external pedestrian door placed in the Southwest corner. All doors remained closed during the individual test sessions, but were kept open for 90 minutes between test sessions to provide for airing out of the facility. Air hoses used for blow outs and for charging pneumatic tools were connected to an external air compressor and extended into the building under the South sliding door.

2.2.2. Test Vehicle

The test vehicle used for this study was a 1967 Kaiser Jeep (Federal Stock Number: 2320-921-6365) with a six cylinder engine and four speed manual transmission. This 1.25 ton four-wheel, truck originally used for military purposes, was identified through an extensive search, as still having the original asbestos-containing clutch. At the time of the test, the vehicle's mileage was documented at 13,000 by the owner, who was able to confirm the low mileage and provided a complete history of the vehicle after its release from the military in the early 1970s.

2.2.3. Mechanic's Activities, Equipment and Tasks

An automotive mechanic with 20 years of professional experience performed removal and replacement of the asbestos-containing clutch using standard tools and operating procedures. Specific tools utilized by the mechanic included a pneumatic impact wrench, hand driven sockets, box and open end wrenches, screwdrivers, scrapers and hammers. The air compressor which powered the pneumatic impact wrench was located in an adjacent building. Work coveralls were provided to limit the generation of non-asbestos fibers from the mechanic's clothing. Additionally, the mechanic was outfitted with a harness that was used to carry the PBZ sampling pumps and associated air sampling cassettes.

The work activities were divided into two test sessions: 1) detachment of the transmission and removal of the existing clutch and 2) installation of the replacement asbestos-containing clutch and reattachment of the transmission. Table 2 summarizes the work activities performed by the professional mechanic during the removal and installation of the clutch. After clutch removal, the bell housing and clutch cover were sprayed and cleaned with non-chlorinated solvent, NAPA 4800, to prepare for reinstallation into the test vehicle. Neither a new nor refurbished asbestos-containing clutch disc was available for the installation into the test vehicle. To simulate the handling of a new asbestos-containing clutch disc, a surrogate clutch disc in its original packaging was identified and used for this experiment. The substitute part was a Sachs manual clutch (PAT 2.227.558-2.448.879). The package containing the clutch was marked with an Asbestos Warning tag indicating the presence of asbestos within the automotive part. During the clutch installation testing, this surrogate clutch disc was removed by the mechanic from its packaging, transported to the vehicle's fly wheel and mounted. At this time the surrogate clutch disc was removed and vehicle reassembly continued using the original clutch disc.

2.2.4. Air Sampling and Analysis

Equipment utilized for collecting area air samples during the removal and installation of an asbestos-containing clutch consisted of line operated electric vacuum air pumps which drew air at metered flow rates between 7 to 10 lpm through cassettes containing MCE filters having 0.8 μm pore size and 25 mm diameter. All pump air flow rates were checked before and after testing with a primary standard, (Bios International DryCal Model DC-1) Flow Calibrator. Area air samples were collected at breathing-zone height at varying distances from the truck (Table 3).

The mechanic was outfitted with a body harness to accommodate the wearing of two battery powered portable air pumps (Ametek, Model α1) to collect PBZ samples. These pumps were calibrated at metered flow rates, nominally 2.0 to 2.5 lpm to draw air through cassettes containing MCE membrane filters having 0.8 μm pore size and 25 mm diameter. Cassettes were placed on each shoulder within the worker's PBZ. All samples were analyzed using PCM following NIOSH Method 7400 and "A" counting rulers (NIOSH, 1994a). Further analysis was also done using TEM following NIOSH Method 7402 (NIOSH, 1994b), and the combined results of analysis were used to calculate asbestos corrected airborne fiber concentrations.

2.2.5. Bulk Sampling and Analysis

Bulk samples were collected to confirm the presence of asbestos within both the vehicle's original clutch and the surrogate clutch disc. From the original clutch, three bulk samples were collected. The first sample was obtained by drilling small holes into the sides of the clutch disc. Another bulk sample consisted of the dust scraped from the seams of the clutch facing. The third sample was debris removed from the bell-housing. A separate bulk sample was taken of the friction material on the surrogate clutch disc. All bulk samples were analyzed using Polarized Light Microscopy (PLM) following EPA Method 600/R-93/116 (Perkins and Harvey, 1993). PLM is capable of identifying the individual components of a sample and estimating their relative concentration within the sample's matrix, allowing differentiation of the individual serpentine and if present, amphibole fibers.

2.3. Statistical Analysis

Airborne asbestos concentrations for the individual exposure tests were analyzed using descriptive statistics. The means and standard deviations for PBZ and area air samples were calculated. Several air samples collected during the seam sealant exposure assessment were at or below the analytical limit of detection (LOD). These values are unusable for statistical purposes but must be considered to limit data censorship (Finkelstein and Verma, 2001). For this study, when performing statistical analysis of the overall data set, the upper values of the detection limits were applied as actual exposure values. Application of the LODs within the data set may have resulted in slightly exaggerated exposure estimates (Glass and Gray, 2001). According to Helsel (1990) the overestimation of the summary statistics by this method is approximately 10%. Using this approach provides a "worst-case" estimate of the airborne asbestos exposure levels generated during this study.

The 8-Hour time weighted average (8-hr TWA), in addition to mean fiber and asbestos concentrations, were calculated with the formula prescribed by OSHA (1997).

3. Results

3.1. Seam Sealant Exposure Assessment

3.1.1. Area Air Samples

A summary of the results of analysis for the area air samples collected during removal of asbestos-containing seam sealant is presented in Table 4. Those area air samples collected at 50-foot distance from the wheel wells (n=14) showed no asbestos fibers detected at the analytical LOD's which averaged 0.0037 f/cc. For area samples collected 5-feet distant from the wheel well test sites, 84% (n=59) showed no asbestos fibers detected at the analytical LOD's. The overall average airborne asbestos fiber concentration for this 70 sample group was 0.0054 f/cc.

3.1.2. Personal Breathing Zone Samples

Table 5 presents the results of analysis for the PBZ samples. Results show asbestos fiber concentrations for both the manual and pneumatic tool assisted techniques employed. Seventy-two percent (n = 10) of the PBZ samples collected during this study showed no asbestos fibers detected at the analytical LOD's. The mean asbestos fiber concentrations for PBZ samples collected during the hand scraping and pneumatic chipping of the sealant were 0.0061 and 0.0059 f/cc, respectively.

Approximately 20 % (n = 19) of all PBZ and area air samples (n = 98) were found to contain chrysotile asbestos fibers which satisfied all relevant counting criteria. No amphibole fibers were detected within any of the air samples collected. The majority of air samples found to contain asbestos fibers were collected during pneumatic chipping of seam sealant. Table 6 summarizes the mean PCM and TEM derived airborne asbestos fiber concentrations for PBZ, area, and the overall combined sample set. The highest PCM and asbestos fiber concentrations of 0.0487 and 0.0134 f/cc, respectively, were observed in PBZ samples.

3.1.3. Bulk Samples Analyses

Bulk samples of seam sealant were collected from the test vehicles in several locations including wheel wells, engine compartment, trunk and underpinning. In total, 13 samples were collected and analyzed using TEM. Table 7 illustrates the collection locations and asbestos content associated with each seam sealant bulk sample. Asbestos contents ranged from 5.9 to 28 % of sample weight. The right side of the Mustang Coupe's trunk contained the highest amount of asbestos. No amphibole asbestos species were detected within any of the samples collected.

3.2 Clutch Exposure Assessment

3.2.1. Area Air Samples

Eight area air samples were collected during the removal and installation of an asbestos-containing clutch in the test vehicle. Table 8 provides a descriptive summary of the air sampling results. The combined duration of the two test sessions was 321 minutes. The mean airborne fiber concentration as detected using PCM for air samples collected during clutch removal was 0.0122 f/cc. When analyzed using TEM, no asbestos fibers were identified in any of these samples. The mean PCM airborne fiber concentration detected during installation of the replacement clutch and subsequent vehicle reassembly, was 0.018 f/cc. TEM analysis of collected air samples indicated the presence of chrysotile fibers in two of the area air samples collected and the resulting asbestos corrected airborne fiber concentrations for these samples were 0.0009 and 0.0011 f/cc. The PCM and asbestos corrected airborne fiber concentrations for all area samples (n = 8) were 0.0151 and 0.0003 f/cc, respectively. The asbestos corrected airborne fiber concentration found at the median was almost 1000 times lower than the current OSHA 8-hr TWA PEL for asbestos.

3.2.2. Personal Breathing Zone Samples

Table 9 presents the airborne fiber concentrations for PBZ samples collected during the two test sessions. Chrysotile fibers were detected only in samples collected during the installation of the replacement clutch, and the mean PCM and asbestos corrected fiber concentrations for all PBZ samples were 0.039 and 0.0014, respectively. None of the PBZ samples showed airborne fiber concentrations which equaled or exceeded the current OSHA 8-hr PEL for asbestos.

3.2.3. Samples Identified to Contain Asbestos

Approximately 33% of the air samples collected during clutch installation contained chrysotile asbestos fibers. No asbestos fibers were detected in samples collected during the removal of the clutch. Table 10 provides data for the samples containing asbestos. During handling of the new asbestos-containing clutch, the airborne fiber concentrations observed within PBZ samples remained below the current OSHA 8-hr TWA and 30-minute excursion level PELs.

3.2.4 Bulk sample analyses

Bulk sample analysis of the original vehicle clutch material and debris was performed to verify the existence of an asbestos-containing unit, and further characterize the asbestos content of clutch wear materials. Table 11 summarizes the results of PLM analyses for all bulk samples (n = 3) collected from the original clutch and the single bulk sample from the surrogate clutch disc. Chrysotile asbestos fibers were detected in the friction material and disc retained wear dust removed from the original clutch disc in concentrations of 30% and 5% (by area), respectively. No asbestos fibers were identified in the residue removed from the bell housing. Analysis using PLM of the surrogate clutch friction material indicated the presence of 45% chrysotile asbestos (by area). No other asbestos fiber types were observed, however the analyst did report the presence of 30% synthetic fibers (by area). No amphibole fibers were detected in these samples.

4. DISCUSSION

4.1. Seam Sealant Exposure Assessment

The potential for release of fibers from asbestos-containing automotive parts and materials during vehicle maintenance activities has been considered an occupational health hazard for vehicle mechanics and garage workers. The majority of published studies focus on the assessment of asbestos exposure associated with brake linings and pads. Prior to the present investigation, no exposure assessments were reported regarding the airborne asbestos exposure levels encountered by mechanics during the removal of asbestos-containing undercoatings, seam sealants or when replacing asbestos-containing clutches.

Bulk sample analysis of the mastic type seam sealer material used on vehicles subject of this study, showed chrysotile asbestos contents ranging from 5.6 to 28% by weight (Table 7). Despite the relatively high concentration of chrysotile fibers detected within bulk samples the mean airborne asbestos fiber exposure levels for PBZ samples was 0.006 f/cc (Table 5). Several air samples collected showed no asbestos fibers present at the LOD. These observations indicate that asbestos fibers are not easily liberated from their asphalt based matrix despite the use of aggressive removal techniques, including pneumatic chiseling. This conclusion is supported by Figure 1 that illustrates asbestos fibers held within the matrix of the seam sealant.

Approximately 69% of area air samples that were collected during the pneumatic chipping of the sealant material from the test vehicles, contained chrysotile asbestos fibers (Table 6). The impact force of the tool liberated asbestos fibers from the matrix of the sealant more easily as compared to the hand scraping method. Thus, utilization of the manual technique for removing the sealant limits exposure potential.

4.2 Clutch Exposure Assessment

The highest asbestos corrected airborne fiber concentration observed during this present study was 0.0028 f/cc, averaged over the 191 minute time period required for clutch installation and vehicle reassembly. Absent any further exposure for the balance of the work day, a 0.0011 f/cc 8-hr TWA would result. Hickish and Knight (1970) reported a 0.79 f/cc TWA airborne fiber exposure for a mechanic performing clutch repairs on a truck. During the first 1.5 to 2 hours of the clutch work, another mechanic was using compressed air blowout to clean the brakes on a second truck located in an adjacent service bay. During the brake cleaning the second mechanic experienced a 7.09 f/cc airborne fiber exposure concentration, and the clutch mechanic was exposed to a 2.25 f/cc concentration. For the 5-hour period after cessation of brake cleaning activities a 0.11 f/cc average concentration was indicated for the clutch mechanic. It is clear from these data that background concentrations generated by truck brake cleaning were the primary contributors to the clutch mechanic's exposure. All of the airborne fiber concentration data reported by Hickish and Knight (1970) were derived using PCM, thus no asbestos correction has been made.

Yeung et al. (1999) reported finding less than 0.05 f/cc during a 125 minute clutch repair job conducted without use of exposure controls. When subsequently reanalyzed using TEM, no asbestos fibers were found at the 0.01 f/cc detection limit. This is despite use of 8800x magnification which allowed a particle resolution limit of 0.02 μm. The work by Boelter et al. (2007) involved heavy construction type equipment which differed significantly from passenger and utility type vehicles in terms of size and necessary work practices for clutch replacement. Also, the mechanics involved in this study performed a variety of other repair activities in conjunction with any clutch related work. For those mechanics involved in clutch repairs, the range of asbestos adjusted exposures varied from 0.011 to 0.052 f/cc for sampling times ranging from 336 to 574 minutes.

Cohen and Van Orden (2008) studied the removal of manual clutch systems from salvage vehicles obtained at automobile recycling facilities. Subject vehicles included 7 passenger cars, 4 light duty trucks, 2 passenger vans, 1 school bus and a dump truck.

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Cohen and Van Orden (2008) studied the removal of manual clutch systems from salvage vehicles obtained at automobile recycling facilities. Subject vehicles included 7 passenger cars, 4 light duty trucks, 2 passenger vans, 1 school bus and a dump truck.

Personal air samples were collected during the actual time periods of clutch removals which ranged from 26 to 161 minutes duration. Analysis of collected personal samples showed a range of asbestos corrected airborne fiber concentrations from 0.015 to 0.13 f/cc with a mean of 0.047 f/cc. Using data derived from a telephone survey of automobile mechanics, the authors were able to apply task length and clutch repair frequency data, and derive incremental contribution 8-hr TWA exposure data finding a range from 3.75 x 10^{-5} f/cc to 0.03 f/cc with a mean of 0.0016 f/cc.

Jiang et al. (2008) studied the handling, unpacking, and repacking of new asbestos-containing clutch discs. Air samples taken during these various activities showed a range of asbestos adjusted airborne fiber concentrations. Those activities which most closely duplicate a mechanic's handling of clutch discs during a replacement process caused 8-hr TWA airborne fiber concentrations ranging from 0.002 to 0.006 f/cc.

The results of this current study compare favorably with the published literature when considering similar work activities on like vehicles. The 0.0028 f/cc airborne fiber concentration is approximately 100 times lower than the current OSHA 8-hr TWA PEL. The results of our investigation indicate that mechanics may be exposed to extremely low levels of airborne asbestos during the servicing of manual automotive clutches using standard operating procedures.

Multiple studies have reported excessive asbestos exposures for workers employed to refurbish asbestos-containing friction materials, including clutches (Levin et al., 1989, 2003; Sakai et al., 2006). Rebuilding/relining of automotive friction materials frequently involves mechanical stripping of the worn brake linings and clutch faces in addition to machine grinding of the surfaces to refurbish these automotive parts. Airborne fiber concentrations ranging between 0.025 and 76.4 f/cc have been reported during these activities (Sakai et al., 2006). However, these activities and workplace conditions are unique to refurbishing facilities and do not occur during the regular removal and replacement of asbestos-contained clutch assemblies.

Chrysotile fibers were identified in 33% of the air samples associated with the clutch installation and vehicle reassembly. Amphibole fibers were not detected within any air or bulk sample collected during the current investigation. These findings mimic the results reported by Jiang et al. (2008) of the absence of amphibole fibers in air samples collected during the stacking, packing and unpacking of asbestos-containing clutch discs. Moreover, no published study was identified that reported the presence of amphibole fibers within any asbestos-containing automotive materials including brakes, clutches and gaskets. The combination of these findings is supportive of the theory that asbestos-containing automotive materials were historically manufactured from chrysotile fibers that were not contaminated with tremolite or other amphibole asbestos.

It appears that the greatest potential for exposure to asbestos during the removal and replacement of asbestos-containing clutches begins with initial handling of the new clutch and ends once the clutch disc is secured behind the pressure plate. No additional exposure is expected after the clutch disc has been so secured.

5. CONCLUSION

This study expands the currently available exposure data for asbestos containing automotive materials providing further evidence that mechanics employed within the automotive repair industry encountered low levels of asbestos exposure during standard repair activities. In particular, the airborne asbestos concentrations observed during the servicing of vehicles assembled with asbestos-containing seam sealant and clutch discs are comparable to the levels associated with brake components and gaskets.

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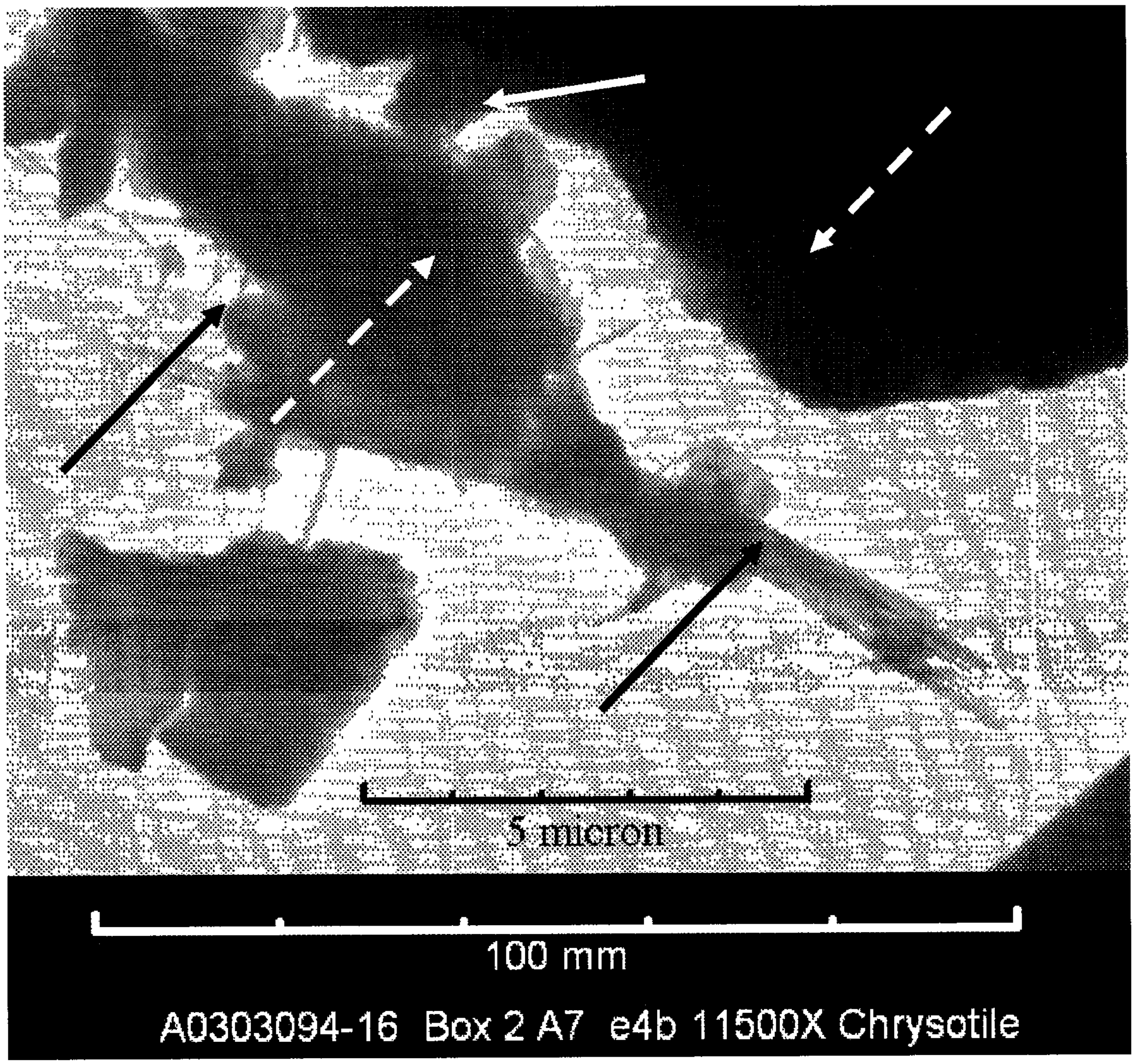
Figure 1: Transmission Electron Micrograph of Chrysotile Fibers Suspended in Asphalt-Based Seam Sealant



Broken arrows indicate sealant matrix; Solid arrows indicate the location of fibers suspended within sealant matrix.

Table 1. Locations of Seam Sealant Bulk Sampling

Test Vehicle	Sample Location
1967 Ford Mustang Coupe	Front left wheel well Front right wheel well Left rear wheel well Interior passenger's side floor Interior driver's side floor Right side of trunk Underside of car; driver's side
1967 Ford Mustang Fastback	Front left wheel well Front right wheel well Engine compartment, right seam seal Trunk; right side Engine compartment, right side thin layer

Table 2. Work Activities Performed during Clutch Removal

Task	Description
Transmission Detachment and Removal of Clutch	1. Disassembly of the top of the transmission housing including removal of the gear shifter and transmission pan. 2. Removal of drive shaft and crossbars to provide access to the bell housing. 3. Disconnection of the transmission. 4. Transmission lowered and moved back. 5. Bell housing opened. 6. Pressure plate, clutch forks and housing removed. 7. Removal of the clutch disc from clutch housing. 8. Detachment of linkage rods from bell housing.
Installation of Clutch and Reattachment of Transmission	1. Replacement clutch removed from packing and placed beneath test vehicle. 2. Clutch placed within housing with a centering pilot. 3. Transmission moved inline with the clutch disk. 4. Slide transmission connected via bolts to the bell housing. 5. Transmission cross member reattached. 6. Front and rear drives installed. 7. Linkage and gear box shift lid reattached. 8. Clutch adjusted 9. Floor plate and gear shift reinstalled and adjusted.

Table 3. Locations of Area Air Samples during Clutch Exposure Assessment

Sample Number	Location
1	Passenger Side; 4' East of Vehicle
2	Driver Side; 3' 5" West of Vehicle
3	Front of Vehicle; 6' 8" South of Vehicle
4	Rear of Vehicle;1.8 Feet North of Vehicle

Table 4. Average TEM Asbestos Fiber Concentrations for Area Air Samples Collected during Seam Sealant Removal

Description and Location	n[a]	Number of Samples below the LOD [b]	Mean Asbestos Fiber Concentration (f/cc) [c]
Area samples taken at 50-feet from test vehicle	14	14 (100 %)	0.0037
Area samples within 5 feet of test vehicle	70	59 (84 %)	0.0054

[a] (n) = sample number; [b] (LOD)= limit of detection; [c] (f/cc) = fibers/cubic centimeter of air

Table 5. Average TEM Asbestos Concentrations for Personal Breathing Zone Samples

Description	n [a]	Samples below the LOD [b]	Mean Asbestos Fiber Concentration (f/cc) [c]
PBZ [d] samples collected during hand scraping of seam sealant	7	6 (86 %)	0.0061
PBZ samples collected during pneumatic chipping of seam sealant	7	4 (66 %)	0.0059
All PBZ air samples	14	10 (72 %)	0.0060

[a] (n) = sample number; [b](LOD) = limit of detection; [c] (f/cc) = fibers/cubic centimeter of air; [d] (PBZ) = personal breathing zone

Table 6. Average PCM and TEM Derived Concentrations for Air Samples Containing Asbestos Fibers

Sample Type	n [a]	Mean PCM [b] (f/cc) [c]	SD [d]	Range	Mean TEM [e] (f/cc)	SD	Range
PBZ [f]	3	0.0487	0.0210	0.025-0.065	0.0134	0.0065	0.0063-0.019
Area: Pneumatic Chipping	11	0.0245	0.0114	0.0074-0.0046	0.0053	0.0046	0-0.0084
Area: Manual Scraping	5	0.0129	0.0064	0.0024-0.018	0.0006	0.0013	0-0.0028
All Air Samples	19	0.0253	0.0163	0.0024-0.065	0.0053	0.0058	0-0.0084

[a] n = (sample number); [b] (PCM) = phase contrast microscopy; [c] (f/cc) = fibers/cubic centimeter of air; [d] (SD) = standard deviation; [e] (TEM) = Transmission Electron Microscopy; [f] (PBZ) = personal breathing zone

Table 7. Bulk Sample Analyses of Seam Sealant Material

Test Vehicle	Location	Asbestos Content by Weight (%)
Mustang Coupe (VIN: 7R01C102182)	Front left wheel well	16
	Front right wheel well	12
	Left rear wheel well	19
	Interior passenger's side floor	5.9
	Interior driver's side floor	7.6
	Right side of trunk	28
	Underside of car on driver's side	11
Mustang Fastback (VIN: 7F02C105118)	Trunk, right side	20
	Trunk, left side	17
	Front left wheel well	6.7
	Front right wheel well	18
	Engine compartment, right side seam	19
	Engine compartment, right side thin layer	5.6

Table 8. Area Air Samples Collected during the Clutch Study

Work Activity	n [a]	Duration (min) [b]	Mean PCM [c] (f/cc) [d]	Mean PCM 8-HR TWA [e] (f/cc)	Mean (f/cc)	Mean asbestos corrected fiber concentration [f] 8-HR TWA [g] (f/cc)
Clutch removal	4	127	0.0122	0.0032	0	0
Clutch installation	4	194	0.018	0.0048	0.0005	0.0002
Clutch removal and installation	8	321	0.0151	0.004	0.0003	0.0001

[a] (n) = (sample number); [b] (min) = minutes; [c] (PCM) = phase contrast microscopy; [d] (f/cc) = fibers/cubic centimeter of air; [e] (TWA) = time weighted average; [f] (Asbestos corrected fiber concentration) = TEM derived asbestos fiber ratio multiplied by the PCM concentration; [g] (8-HR TWA) = 8-Hour time weighted average