Ann. Occup. Hyg., 2015, Vol. 59, No. 3, 292–306
doi:10.1093/annhyg/meu093
Advance Access publication 13 November 2014

The Chartered Society for Worker Health Protection

Asbestos Exposure among Transmission Mechanics in Automotive Repair Shops

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Submitted 21 March 2014; revised 2 October 2014; revised version accepted 9 October 2014.

ABSTRACT

Objectives: Asbestos has been used in a broad variety of industrial products, including clutch discs of the transmission system of vehicles. Studies conducted in high-income countries that have analyzed personal asbestos exposures of transmission mechanics have concluded that these workers are exposed to asbestos concentrations in compliance with the US Occupational Safety and Health Administration (US OSHA) occupational standards. Clutch facings are the friction component of clutch discs. If clutch facings are sold separated from the support, they require manipulation before installation in the vehicle. The manipulation of asbestos containing clutch facings is performed by a group of mechanics known as riveters, and includes drilling, countersinking, riveting, sanding, and occasionally grinding, tasks that can potentially release asbestos fibers, exposing the mechanics. These manipulation activities are not reported in studies conducted in high-income countries. This study analyzes personal asbestos exposures of transmission mechanics that manipulate clutch facings.

Methods: Air sampling campaigns in two transmission repair shops (TRS) were conducted in November 2012 and July 2013 in Bogotá, Colombia. Four workers employed in these TRS were sampled (i.e. three riveters and one supervisor). Personal samples (n = 39), short-term personal samples (n = 49), area samples (n = 52), blank samples (n = 8), and background samples (n = 2) were collected in both TRS during 3–5 consecutive days, following US National Institute for Occupational Safety and Health (US NIOSH) methods 7400 and 7402. Asbestos samples were analyzed by an American Industrial Hygiene Association accredited laboratory.

Results: On at least one of the days sampled, all riveters were exposed to asbestos concentrations that exceeded the US OSHA permissible exposure limit or the Colombian permissible limit value. Additionally, from the forty-seven 30-min short-term personal samples collected, two (4.3%) exceeded the US OSHA excursion limit of 1 f cm^{-3}.

Conclusions: In this study, we identified that the working conditions and use of asbestos containing transmission products expose transmission mechanics to asbestos concentrations that exceed both the Colombian and OSHA standards. The potential consequences for the health of these workers are of great concern.

KEYWORDS: asbestos, chrysotile, clutch disc, Colombia, exposure assessment, transmission mechanics

INTRODUCTION

Asbestos-containing materials are good acoustic, heat and fire insulators, and resist thermal, biological, and chemical attack (Thompson and Mason, 2002). Because of these characteristics, asbestos has been used in a wide range of industrial products such as thermal insulations, friction products (e.g. brake and transmission products of vehicles), building materials, and heat-resistant textiles (Pierce *et al.*, 2008).

A causal association between asbestos exposure and several diseases has been established (IARC, 1998). The International Agency for Research on Cancer (IARC) has classified all types of asbestos (i.e. chrysotile and amphiboles) as carcinogenic to humans (Group I; IARC, 1998). Some of the diseases that might result from the inhalation of asbestos fibers include lung cancer, asbestosis, and mesothelioma (Kanarek, 2011). Every year asbestos exposure is responsible for half of the occupational cancer deaths worldwide (OMS, 2004).

In 2011, the Colombian Ministry of Social Protection established for the first time an asbestos occupational standard (i.e. Resolution 007, 2011) (MSPS, 2011). In Resolution 007, the American Conference of Governmental Industrial Hygienists (ACGIH) threshold limit value (TLV) for asbestos was adopted as the Colombian permissible limit value (PLV). Thus, the Colombian PLV is 0.1 f cm^{-3} for an 8-h time weighted average (TWA) phase contrast microscopy equivalent (PCME) asbestos concentration [We use the term PCME to mean counts corrected for asbestos content, as described below. It is important to note that this is different from the meaning of PCME in ISO 10312:1995 (ISO, 1995)]. In the USA, the Occupational Safety and Health Administration (US OSHA) permissible exposure limit (US OSHA PEL) for asbestos is 0.1 f cm^{-3} for an 8-h TWA PCME concentration. The US OSHA has also established an excursion limit (US OSHA EL) of 1 f cm^{-3} PCME asbestos concentration for a 30-min exposure period (OSHA, 2013). [Instead of using the term US OSHA EL, we previously used the term 'short term exposure limit (STEL)' (Cely-García *et al.*, 2012, 2014).]

Asbestos containing clutch parts have been used since the early 20th century (Cohen and Van Orden, 2008; Jiang *et al.*, 2008). Traditionally, chrysotile was the type of asbestos used in clutch parts, comprising 30–60% of the friction material (Yeung *et al.*, 1999; Jiang *et al.*, 2008). Amphiboles have not been detected in previous studies of transmission mechanics (Blake *et al.*, 2008; Jiang *et al.*, 2008). Beginning in the 1980s, chrysotile was gradually replaced in clutch products used in the USA with other non-asbestos substitutes (Jiang *et al.*, 2008).

In 1975, the US National Institute for Occupational Safety and Health (US NIOSH) warned about the potential risk of asbestos exposure of workers that handled asbestos containing brake parts and clutch discs (NIOSH, 1975). In addition, several exposure assessment studies conducted in Australia and USA have concluded that transmission mechanics are exposed to asbestos concentrations in compliance with both the US OSHA PEL and EL (Yeung *et al.*, 1999; Boelter *et al.*, 2007; Blake *et al.*, 2008; Cohen and Van Orden, 2008; Jiang *et al.*, 2008). These studies describe the activities performed by transmission mechanics as only removing the entire old clutch disc and replacing it with a new one (Boelter *et al.*, 2007; Blake *et al.*, 2008; Cohen and Van Orden, 2008). Nevertheless, there is a study conducted in Japan during the 1980s and published in 2006, that reports high PCM concentrations due to the manipulation activities (i.e. machine grinding and leveling) of brake linings and clutch facings in three companies involved in the reprocessing of automobile brakes and clutches (Sakai *et al.*, 2006).

Previous studies of our research group conducted on brake mechanics in Bogotá found that the manipulation of asbestos containing brake products (e.g. grinding, drilling) resulted in the release of important amounts of asbestos fibers, exposing the workers (Cely-García *et al.*, 2012, 2014). Transmission mechanics could be facing a similar situation, since asbestos containing clutch facings (i.e. the friction component of clutch discs), are commercialized in Colombia detached from the clutch plate (i.e. metallic support). The clutch disc is comprised of two clutch facings attached to the clutch plate, and clutch facings that are detached from the plate require manipulation before installation. The current study analyses personal asbestos exposures of transmission mechanics during the manipulation process of asbestos containing clutch facings in Bogotá, Colombia.

METHODS

In 2012, a comprehensive and detailed census of brake repair shops located in an area of the city of Bogotá where automotive repair shops cluster was developed. During the development of this database, three transmission repair shops (TRS) were identified. Two of these shops (i.e. TRS1 and TRS2) collaborated with this study. The study methods and design were approved by the Ethics Committee of Universidad de los Andes, and workers from the TRS that participated in the study signed an informed consent.

Personal partial period, personal 30 min, and area air samples were collected during 3 consecutive days in TRS1 (8–10 November 2012), and 5 consecutive days in TRS2 (11–15 July 2013), during the work-shift. To reduce the chances of overloading the filters during the collection of air samples, the work-shift was divided into shorter partial-period sampling windows. Air sample collection and analysis followed US NIOSH methods 7400 (NIOSH, 1994a) and 7402 (NIOSH, 1994b). US NIOSH method 7400 provides fiber counts using phase contrast microscopy (PCM), and reports total fiber concentration according to selected counting rules. US NIOSH method 7402 utilizes transmission electron microscopy (TEM) to determine fiber identity and provides asbestos fiber counts, asbestos type, and the fraction of observed fibers that are asbestos.

Personal samples were collected in a group of TRS workers known as riveters, who manipulate asbestos and non-asbestos containing clutch facings to attach them to the clutch plate before installation in the vehicle. In TRS1, there were two riveters (R1, R2) in charge of the manipulation of clutch facings, and sporadically, depending on the amount of work, a third worker (W1) who is the supervisor of the TRS, also performed manipulations. In TRS1, workers R1, R2, and W1 did not repair the transmission system of the vehicles; they only prepared the transmission parts in order to install them in the vehicles, and did not use any compressed air. The workers in charge of repairing the vehicle's transmission system worked in a different area, and were not sampled. In TRS2, the riveter (R3) conducting the manipulation processes was also the mechanic in charge of repairing the vehicle's transmission system. R3 reported that he does not clean the vehicle's transmission system. Although repairing the transmission system of the vehicle could involve the use of compressed air or rags to clean the system, this was not the case for the workers sampled in this study. To avoid study-induced bias from the sampling campaign, all workers were instructed to conduct their daily activities without modifications. The activities performed were recorded in activity diaries. Short-term personal samples were collected during the manipulation activities of clutch facings, and during cleaning activities. The duration of the partial period sample was longer when no manipulations were conducted, since air fiber concentrations were expected to be low. Blank samples were collected for each sampling day, and background samples were collected during one night at each shop. All personal samples were analyzed by PCM and TEM. Background and blank samples were analyzed by PCM.

Study design and methods were similar to those used in previous studies by our research group (Cely-García *et al.*, 2012, 2014). Air samples were collected using AIRChek XR5000 pumps (SKC-Inc., Eighty Four, PA, USA) operated at a flow rate of ~2 LPM, connected to 25-mm cassettes equipped with 50 mm conducting extension cowls, holding 25-mm MCE filters with 0.45 µm pore size(SKC Preloaded Cassette, SKC-Inc.). Flow rates were calibrated at the beginning and at the end of each sampling window using a Defender 510 High or 520 High BIOS International Calibrator (BIOS International, Butler, NJ, USA) following standard procedures. Samples were reported as suspect if the difference between the initial and final flow was above 5%.

Samples were analyzed by Forensic Analytical Laboratories, Inc. (Forensic Analytical Laboratories, Inc, Hayward, CA, USA), an American Industrial Hygiene Association (AIHA) accredited laboratory that also participates in the National Voluntary Laboratory Accreditation Program (NVLAP). TEM analysis was performed at 100 kV accelerating voltage and ~2500× magnification to count fibers >5 µm, using a Philips CM12 TEM (Eindhoven, Netherlands, installed in ~1991). A magnification of 10 000× was used to determine fiber dimension and countability of fibers close in length to 5 µm. The energy dispersive X ray analyzer (EDXA) instrumentation was manufactured by Evex (Princeton, NJ, USA; installed in 2007), and consists of a quantum dot detector (QDD) with standard window and digital ADC/MCA analyzer and Q-Dot power supply (Forensic Analytical Laboratories, personal communication).

PCME personal concentrations were used to compare against both the Colombian and the US OSHA standards. To estimate PCME concentrations, PCM concentrations were corrected with the fraction of asbestos fibers to total fibers (f/F) reported by TEM (NIOSH, 1994b). [Note that this usage of the term PCME is different from that in ISO 10312:1995 (ISO, 1995)].

The US OSHA PEL and Colombian PLV set limits for asbestos personal exposures during work-shifts of 8-h per day. Nevertheless, in multiple occupations in Colombia, as happened with the mechanics involved in the current study, the daily work-shift is longer. The approach to deal with work-shifts extending beyond 8 h differs between the two standards (i.e. US OSHA PEL and Colombian PLV). One of the options recommended in the US OSHA Technical Manual is using the worst partial period sampling windows that add up 8 h for each work-shift to estimate the 8-h TWA PCME concentration, for comparison purposes against the US OSHA PEL (OSHA, 2008). This approach was used in the current study. For short-term personal samples, the 30-min PCME personal concentrations were compared against the US OSHA EL of 1 f cm^{-3}.

In the case of the Colombian PLV, the regulation stipulates that when the work-shift exceeds 8 h, the PLV must be adjusted following equations (1) and (2) (MSPS, 2011):

$$\mathrm{CF} = \left(\frac{8}{\mathrm{hd}}\right)\left(\frac{24-\mathrm{hd}}{16}\right) \qquad (1)$$

$$\mathrm{PLVc} = \mathrm{CF} \times \mathrm{PLV} \qquad (2)$$

where CF is a correction factor, hd is the number of hours worked per day, and PLVc is the corrected PLV.

In TRS1 the work-shift was 8.5 h/day, and in TRS2 was 9 h/day. For comparison purposes against the Colombian PLV, the adjusted PLV is 0.091 f cm^{-3} for TRS1 and 0.083 f cm^{-3} for TRS2.

When PCM concentrations were below the limit of detection (LOD), one-half of the LOD was used for calculation purposes. To determine the potential impact of using one-half of the LOD instead of the LOD, a sensitivity analysis was conducted in personal samples with sampling windows that had concentrations below the LOD. The sensitivity analysis showed that using the LOD instead of one-half of the LOD did not result in important differences on the 8 h PCME concentrations. In fact, the sensitivity analysis showed that the compliance status of the samples did not change when using the LOD instead of ½ LOD. When work-shifts ended before 8 h or the worker left the shop, fiber concentrations were assumed as 0 f cm^{-3} for the time remaining to complete the work-shift.

Area samples were collected in both shops at a breathing height of 1.5 m. In TRS1, the collection of area samples was done to determine if fibers could migrate outside the manipulation area (MA), exposing administrative staff or customers. In TRS1, the office facilities were physically separated from the manipulation area, and area samples with a duration of ~8 h were collected at the office entrance (OF), and at the MA. TRS2 did not have physically separated areas, since this shop only had one large area where both administrative and repair activities were conducted. To assess fiber migration in TRS2, short-term area samples were collected at 1 m (A1) and 2 m (A2) from the manipulation equipment (i.e. emery disc), simultaneously to the short-term personal samples collected during the manipulation processes. Fig. 1 shows the location of the area samples in each TRS.

All area samples were analyzed by PCM, and in TRS2, area samples collected at 1 and 2 m during days in which the 8 h personal concentration exceeded the US OSHA PEL, were also analyzed by TEM (i.e. Day 1 and 2).

Asbestos percent bulk content of the most common clutch facings used in the shops sampled was determined using method EPA 600/R-93-116 PLM, by Forensic Analytical Laboratories. None of the labels of the clutch facings specified asbestos content. However, we received feedback from the workers regarding their perception of asbestos content. Two of the brands sent for analysis were reported as asbestos containing products, and the third brand was reported as asbestos free. To capture potential variability of asbestos content, four clutch facings per brand were analyzed.

Temperature and relative humidity were recorded on MAs using a HOBO U10 Temperature Relative Humidity Data Logger U10-003 (ONSET, Bourne, MA, USA).

RESULTS

Description of the TRS

TRS1 operates ~8.5 h per day on weekdays, and 5 h on Saturdays. TRS2 operates ~9 h from Monday to

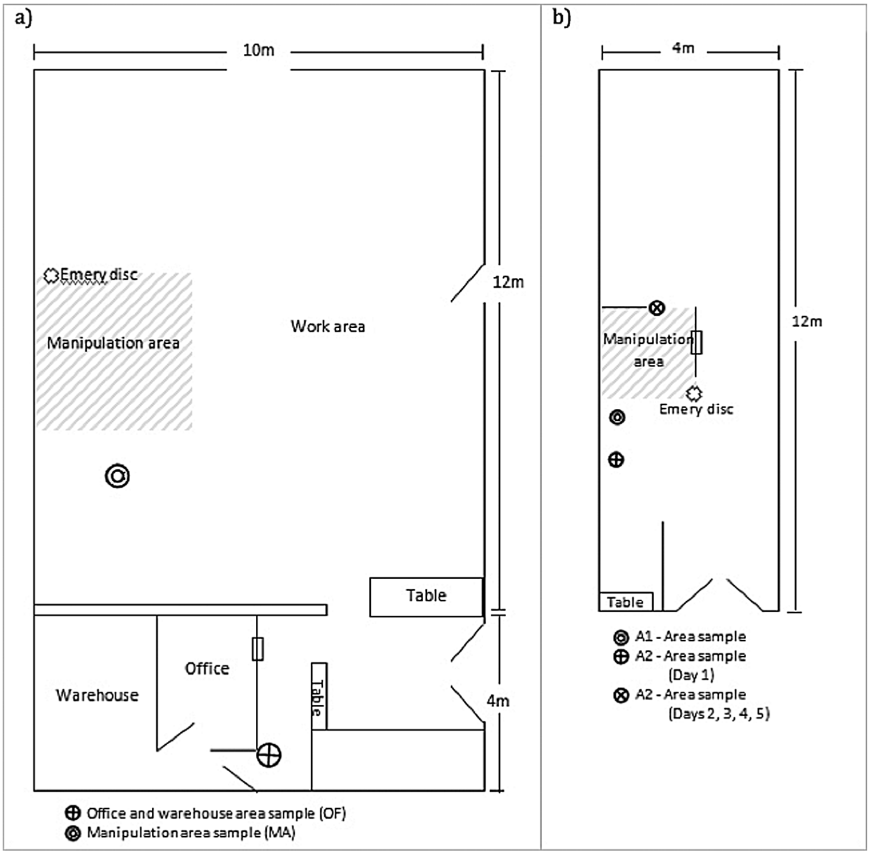

Figure 1 (a) Location of area samples in TRS1 (vertical view). (b) Location of area samples in TRS2 (vertical view).

Saturday. Both TRS use asbestos containing clutch facings, and TRS1 sporadically uses non-asbestos containing clutch facings (i.e. glass fiber). Table 1 presents a description of the TRS involved in the study.

Description of manipulation activities of clutch facings

At the TRS sampled, clutch facings are sold without holes and separated from the clutch plate. Using the activities diaries kept during the sampling campaigns, it was possible to reconstruct the tasks involved in the manipulation process required to attach clutch facings to the clutch plate. The manipulation process of clutch facings is the same for all types of manual transmissions (i.e. both heavy and passenger vehicles). Once the clutch disc has been uninstalled from the transmission system, the manipulation process starts with the removal of the rivets from the old clutch facings using a drill. The new clutch facings are attached to the old clutch plate using a wrench, and holes are drilled in the clutch facings matching the holes of the clutch plate. Then, the holes on the clutch facings are countersunk, and if drilling the clutch facings leaves an irregular surface surrounding the holes, the surface is sanded. In TRS2, the riveter rubbed one clutch facing against the other to remove the debris. Subsequently, the clutch facings are riveted to the plate. If the size of the facings does not match the plate, facings are ground with an emery disc.

Sometimes clutch facings for specific vehicles are not commercially available or they are not in stock. In such occasions, riveters need to adjust clutch facings of improper size to the clutch plate, which includes cutting the edges, grinding, and sanding the products. A flowchart of the manipulation process is presented in Fig. 2.

Air samples results

A total of 150 samples were collected in the TRSs, including 39 personal samples of different duration,

Table 1. Description of TRS

Shops characteristics	TRS1	TRS2
Type of vehicles serviced	Prepares transmission parts for heavy and passenger vehicles serviced at the shop and at other nearby TRS.	Prepares transmission parts for passenger vehicles exclusively serviced at the shop.
Number of clutch discs manipulated per day	~12	~1
Workers involved in clutch discs preparation	2 Riveters (R1, R2)	1 Riveter (R3)
	1 Supervisor (W1)	
Area of the shop, ceiling height	~160 m^2 with a ceiling height between 3.5 and 4.5 m.	~48 m^2 with a ceiling height ~3.5 m
Description of office and warehouse	Office and warehouse area of ~20 m^2, physically separated from the manipulation area. Warehouse access is through the office. Office door located at ~10 m from the manipulation area. The doors of the office and the warehouse remained open during the entire work-shift.	Office and warehouse area shared space with manipulation area. Work desk located at ~3 m from the manipulation area, close to the exit door. Exit door remained open during the entire work-shift.
Description of manipulation area	Area of ~13 m^2. The manipulation area was embedded in a larger area where other mechanics performed their work.	Area of ~4 m^2 with a ceiling height of ~3 m, which was 0.5 m lower than the rest of the shop.
Manipulation equipment and materials	1 drill	1 drill
	1 countersink	1 countersink
	1 rivet machine	1 rivet machine
	1 emery machine (with emery stone and emery disc)	1 emery machine (with emery stone and emery disc)
	Sandpaper	Sandpaper
Ventilation system	Consisted of a self-made extractor hood located above the countersink and rivet machines, which was rarely operated. There are two skylights in the roof, one located above the manipulation area, which remained open during the sampling days. Two exit doors remained open during the entire work-shift.	No ventilation system in the shop, except for the natural ventilation provided by the exit door. This door remained open during the entire work-shift.

Table 1. *Continued*

Shops characteristics	TRS1	TRS2
Cleaning activities of the manipulation area	Every day at the end of the shift the shop was cleaned. This was done after sprinkling small amounts of water on the floor. Occasionally workers removed dust from the machines with their hand or a broom in dry conditions.	Cleaning activities under dry conditions were performed once during the sampling campaign at the end of the week.
Respiratory protection equipment	Workers wore working clothes. In some cases workers used inappropriate respiratory protection, including a piece of cloth or a filtering face-piece respirator to cover their nose and mouth.	Worker wore working clothes. The riveter used a half face-piece air-purifying respiratoron top of a filtering face-piece respirator. Neither respirator met the recommendations for asbestos protection. Respirators were loose, and occasionally the nose was uncovered.

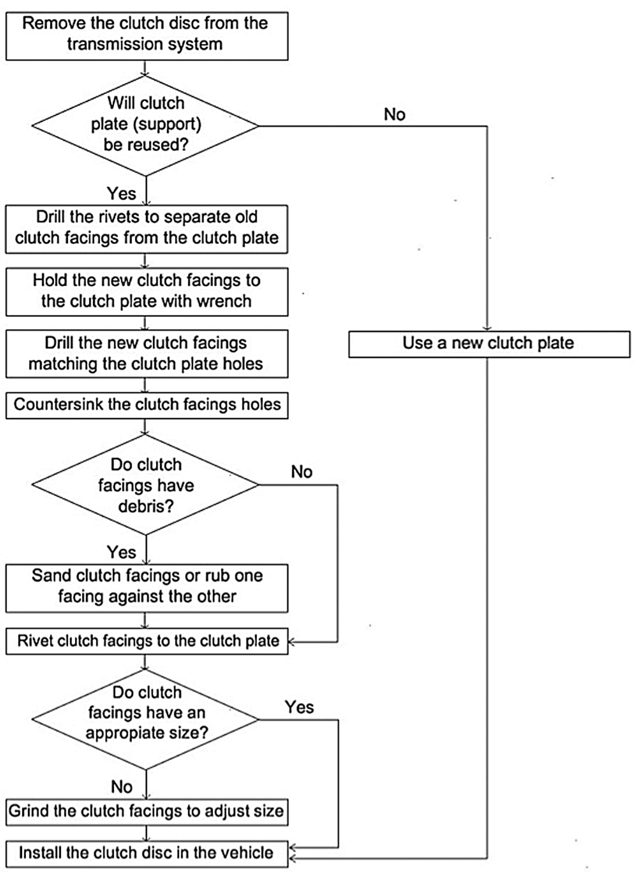

Figure 2 Manipulation process of clutch facings.

49 short-term personal samples, 52 area samples, 8 blanks, and 2 background samples. Chrysotile fibers were the only type of asbestos identified in the samples collected in both TRS. Eleven TEM fiber counts were below the analytical sensitivity. One sample was suspect because the flow drift was greater than 5% (i.e. 5.47%). Another three samples were labeled as suspect because the conducting extension cowls were accidentally opened when detaching them from the pump, although the filter remained in the cowl and the cowl was immediately sealed again. One filter was reported by the laboratory as "loaded with particulates" (i.e. R1 Day1 ST3). All these samples were used in the TWA calculations, and reported in footnotes 'b' and 'g' in Table 2, and footnotes 'd', 'f', and 'g' in Table 3. No fibers were found in the blanks, and both background samples collected had PCM concentrations below the LOD.

During sampling days, temperature in TRS1 ranged between ~15 and 24°C in the MA, and between ~19 and 22°C in the office area. Relative humidity ranged between ~36 and 70% in the MA, and between ~38 and 60% in the office area. In TRS2, temperature and relative humidity were sampled at 1 and 2 m from the manipulation equipment (i.e. A1 and A2, respectively). Temperature ranged between ~17 and 22°C in both sampling points, and relative humidity ranged between~53 and 72% in sample point A1 and between ~47 and 67% in sample point A2.

Personal air samples results

Table 2 presents the results of the 8 h TWA and 8.5 h TWA personal asbestos concentrations in TRS1, for comparison purposes against the US OSHA PEL and the Colombian PLV, respectively. Both riveters sampled in TRS1 were exposed to asbestos concentrations not in compliance with both the US OSHA PEL and the Colombian PLVc during the first sampling day (i.e. R1–Day 1, R2–Day 1), and were exposed to asbestos concentrations above 50% of the US OSHA PEL and the Colombian standard during the second sampling day (i.e. R1–Day 2, R2–Day 2). The supervisor in TRS1 (i.e. W1) was exposed to asbestos concentrations below both US OSHA and Colombian standards in all the days sampled.

Table 3 presents the results of the 8 h TWA and 9 h TWA personal asbestos concentrations in TRS2. Riveter R3 was exposed to asbestos concentrations above both standards during two sampling days (i.e. R3–Day 1, R3–Day 2), and was exposed to asbestos concentrations exceeding 50% of the US OSHA PEL and the Colombian standard during Day 5 (i.e. R3–Day 5). Supplementary Table S1, available at *Annals of Occupational Hygiene* online presents all 30-min short-term personal asbestos concentrations and the description of the manipulation or cleaning activities associated with each sample. For the concentrations presented in Supplementary Table S1, available at *Annals of Occupational Hygiene* online, when the sampling window was shorter than 30-min, 0 f cm^{-3} was assumed for the remaining time. It is important to highlight that all the 30-min PCME short-term personal samples collected in TRS1 were below the US OSHA EL. However, four samples had TEM concentrations above 0.5 f cm^{-3}, and one sample was above 1 f cm^{-3}. Two 30-min PCME short-term personal samples collected in TRS2 exceeded the US OSHA EL of 1 f cm^{-3}. Eleven percentage of all the short-term personal samples collected in both shops were above 50% of the US OSHA EL.

During manipulation activities of asbestos and non-asbestos containing clutch facings, presented in Supplementary Table S1, available at *Annals of Occupational Hygiene* online, workers reported which type of products was used. The asbestos content bulk analysis showed that the two brands reported by the workers as asbestos-containing products had a 20% content of chrysotile. There was no variation in asbestos content between the four clutch facings analyzed per brand. The four clutch facings of the brand reported by workers as asbestos free, had a 25% content of fibrous glass and asbestos were 'non-detected'.

Additionally, Supplementary Tables S2 and S3, available at *Annals of Occupational Hygiene* online present the results of all the personal samples collected in TRS1 and TRS2, respectively.

Table 4 summarizes the 8-h TWA and 30-min PCME short-term asbestos concentrations of personal samples collected in both TRS sampled.

Area air samples results

PCM area concentration results

In TRS1, the three 8-h TWA PCM office area concentrations collected on Days 1, 2, and 3 were 0.009, 0.002, and 0.005 f cm^{-3}, respectively. The corresponding 8-h

Table 2. PCME 8-h TWA and 8.5-h TWA personal asbestos concentrations for workers sampled in TRS1

Worker–Day	Number of sampling windows	Total sampling time (min)	TWA PCME concentration using total sampling time ($f\,cm^{-3}$)[a]	US OSHA STANDARD ($0.1\,f\,cm^{-3}$ for 8-h TWA)		COLOMBIAN STANDARD ($0.091\,f\,cm^{-3}$ for 8.5-h TWA)	
				Time assumed with $0\,f\,cm^{-3}$ to complete 8-h TWA (min)	8-h TWA PCME concentration ($f\,cm^{-3}$)[a]	Time assumed with $0\,f\,cm^{-3}$ to complete 8.5-h TWA (min)	8.5-h TWA PCME concentration ($f\,cm^{-3}$)[a]
R1–Day 1	11	508	0.103	—	0.108[b,c]	2	0,103[b,d]
R1–Day 2	5	495	0.064	—	0.066	15	0.062
R1–Day 3	4	270	0.042	210	0.024	240	0.022
R2–Day 1	12	510	0.107	—	0.111[c]	0	0.107[d]
R2–Day 2	13	480	0.077	0	0.077[b]	30	0.073[b]
R2–Day 3	6	263	0.088	217	0.048	247	0.046
W1–Day 1	2	533	0.013	—	0.013[e]	—	0.013[f]
W1–Day 2[g]	7	553	0.012	—	0.014[b]	—	0.012[b,h]
W1–Day 3	1	285	0.010	195	0.006	225	0.006

R1: Riveter 1, R2: Riveter 2, W1: worker 1.
[a]PCME concentrations calculated based on PCM concentrations, chrysotile fiber counts, and f/F ratio, which are shown in detailed for each sample is available as Supplementary Table S2 at *Annals of Occupational Hygiene* online.
[b]TWA PCME concentration includes sampling window(s) with PCM concentrations <LOD. Total fibers/asbestos fibers ratio was multiplied by one-half of the LOD for sampling window(s) with PCM concentrations <LOD.
[c]8-h TWA PCME concentration not in compliance with OSHA PEL of $0.1\,f\,cm^{-3}$.
[d]8.5-h TWA PCME concentration not in compliance with Colombian PLVc of $0.091\,f\,cm^{-3}$.
[e]8-h TWA PCME concentration calculated using the worst 8-h of the work shift, according with the US OSHA Technical Manual (OSHA, 2008).
[f]Samples were collected during 533 min this day. TWA PCME concentration was estimated for the total sampling time, and compared against the Colombian PLVc of $0.085\,f\,cm^{-3}$.
[g]TWA estimation includes concentrations from samples W1 Day2 P2 and W1 Day2 ST2, in which the conducting extension cowl were accidentally opened at the end of the sample collection. Cowls were immediately closed and the filter always remained in the cowl.
[h]Samples were collected during 553 min this day. TWA PCME concentration was estimated for the total sampling time, and compared against the Colombian PLVc of $0.080\,f\,cm^{-3}$.

Table 3. PCME 8-h TWA and 9-h TWA personal asbestos concentrations for workers sampled in TRS2

Worker–Day	Number of sampling windows	Total sampling time (min)	TWA PCME concentration using total sampling time ($f\ cm^{-3}$)[a]	US OSHA STANDARD ($0.1\ f\ cm^{-3}$ for 8-h TWA)		COLOMBIAN STANDARD ($0.083\ f\ cm^{-3}$ for 9-h TWA)	
				Time assumed with $0\ f\ cm^{-3}$ to complete 8-h TWA (min)	8-h TWA PCME concentration ($f\ cm^{-3}$)[a]	Time assumed with $0\ f\ cm^{-3}$ to complete 9-h TWA (min)	9-h TWA PCME concentration ($f\ cm^{-3}$)[a]
R3–Day 1	7	461	0.159	19	0.153[b,c,d]	79	0.136[d,e]
R3–Day 2	7	475	0.195	5	0.193[b,c,f]	65	0.172[e,f]
R3–Day 3[g]	4	479	0.024	1	0.025[f]	61	0.022[f]
R3–Day 4	4	513	0.032	—	0.034[b]	27	0.030
R3–Day 5	5	523	0.057	—	0.061[b,f]	17	0.050[f]

R3: Riveter 3.
[a]PCME concentrations calculated based on PCM concentrations, chrysotile fiber counts, and f/F ratio, which are shown in detailed for each sample is available as Supplementary Table S3 at *Annals of Occupational Hygiene* online.
[b]8-h TWA PCME concentration calculated using the worst 8-h of the work shift, according with the US OSHA Technical Manual (OSHA, 2008).
[c]8-h TWA PCME concentration not in compliance with OSHA PEL of $0.1\ f\ cm^{-3}$.
[d]TWA PCME concentration includes a suspect sample that had a flow drift of 5.4%, with a sampling time of 30-min and a PCME concentration of $1.084\ f\ cm^{-3}$.
[e]9-h TWA PCME concentration not in compliance with the Colombian PLVc of $0.083\ f\ cm^{-3}$.
[f]TWA PCME concentration includes sampling window(s) with PCM concentrations <LOD. Total fibers/asbestos fibers ratio was multiplied by one-half of the LOD for sampling window(s) with PCM concentrations <LOD.
[g]TWA estimation includes concentration from sample R3 Day3 P3, in which the conducting extension cowl was accidentally opened at the end of the sample collection. Cowl was immediately closed and the filter always remained in the cowl.

Table 4. Statistical summary of PCME personal asbestos concentrations found in the TRS sampled

Type of sample	Worker (shop)	Total number (number above the US OSHA PEL or EL)	PCME asbestos concentrations (f cm^{-3})				
			Mean	SD	Median	Min	Max
8-h TWA personal samples [a]	R1 (TRS1)	3 (1[b])	0.066	0.042	0.066	0.024	0.108
	R2 (TRS1)	3 (1[b])	0.079	0.032	0.077	0.048	0.111
	R3 (TRS2)	5 (2[b])	0.093	0.076	0.061	0.025	0.193
	W1 (TRS1)	3 (0[b])	0.011	0.004	0.013	0.006	0.014
Short-term personal samples [c]	R1 (TRS1)	12 (0[d])	0.172	0.088	0.195	0.021	0.332
	R2 (TRS1)	23 (0[d])	0.105	0.048	0.110	0.022	0.212
	R3 (TRS2)	11 (2[d])	0.603	0.443	0.432	0.223	1.653
	W1 (TRS1)	3 (0[d])	0.065	0.076	0.021	0.021	0.153

R1: Riveter 1, R2: Riveter 2, R3: Riveter 3, W1: worker 1.
[a]Calculated using the 8-h TWA PCME asbestos concentrations shown in Tables 2 and 3 (Column 6).
[b]Values compared against the US OSHA PEL of 0.1 f cm^{-3}.
[c]Based on the 30-min PCME asbestos concentrations shown in Supplementary Table S1 (Column 5) available at *Annals of Occupational Hygiene* online.
[d]Values compared against the US OSHA EL of 1 f cm^{-3}.

TWA PCM MA concentrations collected on Days 1, 2, and 3 were 0.017, 0.010, and 0.015 f cm^{-3} respectively. In TRS2, the 8-h TWA PCM A1 area concentrations ranged between 0.007 and 0.050 f cm^{-3} (i.e. collected during 5 days). For A2, the 8-h TWA PCM area concentrations ranged between 0.006 and 0.183 f cm^{-3} (i.e. collected during 5 days).

PCME area concentration results

Eight-hour TWA PCME area concentrations in TRS2 were estimated for Days 1 and 2 in sampling points A1 (1 m), and A2 (2 m) (Fig. 1), because on these days personal samples showed high asbestos exposures of the riveter (R3). For this analysis, fiber concentration was assumed as 0 f cm^{-3} during periods when samples were not collected. One of these 8-h TWA area concentrations exceeded 0.1 f cm^{-3} (i.e. A2 Day 2 = 0.183 f cm^{-3}), recognizing that area samples should not be used to determine regulatory compliance. The other 8-h TWA PCME area concentrations (A1 Day 1 and 2, and A2 Day 1) had quantifiable asbestos concentrations ranging from 0.024 to 0.050 f cm^{-3}.

Comparison of PCME short-term personal and short-term area concentrations

A preliminary analysis was conducted to determine the migration of fibers in the work area during the manipulation activities. For this, during Days 1 and 2 short-term 30-min area concentrations were collected in TRS2 at points A1 and A2 while riveter was manipulating asbestos containing products. PCME 30-min A1 concentrations ranged between 0.091 and 0.207 f cm^{-3}. Thirty-minute PCME A2 concentrations ranged between 0.069 and 1.715 f cm^{-3}. PCME concentration of sample A2 Day2 ST2 exceeded 1 f cm^{-3}. Recognizing that the number of samples is small, no clear patterns associating asbestos concentration with the distance to the manipulation equipment was observed. Supplementary Table S4, available at *Annals of Occupational Hygiene* online shows in detail the 30-min personal sample PCME concentrations and the corresponding 30-min PCME area samples at a distance of 1 m (A1) and 2 m (A2) from the manipulation equipment.

DISCUSSION

This study describes the manipulation activities of asbestos containing clutch facings performed by riveters. These manipulations are required because clutch facings are sold detached from the support. In the TRS sampled, most of the clutch facings used contained asbestos. Riveters sampled have to perform manipulation activities including drilling, countersinking, riveting, sanding, and grinding clutch facings, which release asbestos fibers and expose workers. All riveters sampled were exposed to non-compliant asbestos concentrations when compared to the US OSHA PEL and the Colombian standard. Moreover, some manipulation activities resulted in asbestos exposures exceeding the US OSHA EL. Although ready to install clutch discs are commercially available, they are more expensive and were less common in the TRSs sampled.

To the best of our knowledge, this is the first study that reports asbestos exposures on transmission mechanics (i.e. riveters) in low- and middle-income countries. The results obtained in this study are different from the results of the small number of studies conducted on this occupational group in high-income countries. In 1999, a study conducted in Sydney, Australia found that during the replacement process of a clutch disc, PCM concentrations were below the LOD (0.05 f cm^{-3}) (Yeung *et al.*, 1999). A study from the USA evaluated personal exposures to asbestos among transmission mechanics during activities that included unpacking, repacking, and stacking boxes, cleaning asbestos containing clutch discs, and clothes handling. This study found that personal asbestos concentrations were in compliance with the US OSHA PEL and EL, and reported that the highest exposures were associated with stacking unopened boxes (Jiang *et al.*, 2008). Another study conducted in USA in 2003 analyzed asbestos exposures during the removal and replacement of asbestos-containing materials in heavy vehicles (i.e. gaskets, brakes, and clutch parts). In this study, authors reported that the PCME short-term personal asbestos concentrations ranged between <0.043 and 0.099 f cm^{-3}, and TWA PCME concentrations ranged between 0.011 and 0.052 f cm^{-3} during different sampling periods (i.e. from 336 to 574 min) (Boelter *et al.*, 2007). Finally, Blake *et al.* (2008) reported that during the installation of a clutch disc, the 8-h TWA PCME chrysotile asbestos concentration was 0.0011 f cm^{-3} (Blake *et al.*, 2008). All these studies concluded that transmission mechanics are not at excess risk of developing asbestos related diseases (Yeung *et al.*, 1999; Boelter et al., 2007; Blake *et al.*, 2008; Jiang *et al.*, 2008). However, none of the previous studies report the manipulation activities conducted by the riveters sampled in the current study. Thus, a potential explanation for the low asbestos exposures reported in studies conducted in high-income countries involve the fact that in these countries, clutch discs can be directly installed in vehicles without manipulating clutch facings. It is important to highlight that there is one study conducted in Japan during the 1980s and published in 2006 that reports manipulation activities on brake linings and clutch facings. Instead of transmission mechanics or riveters, these workers were involved in the reprocessing of automobile brake and clutches (Sakai *et al.*, 2006). Although the occupation was different, workers from the Japanese study and the current study manipulated asbestos containing clutch parts, and asbestos exposures of workers sampled in both studies are extremely high. Unfortunately, the Japanese study only reports PCM concentrations, although they used TEM to identify the type of fibers found (i.e. chrysotile).

As expected, days with the highest number of manipulations resulted in the highest 8-h TWA PCME personal asbestos concentrations. Focusing on the 8-h TWA PCME personal asbestos estimates, 29% (4 out of 14) exceeded both the US OSHA PEL and the Colombian PLVc. Focusing on the PCME 30-min short-term personal samples, 4.1% (2 out of 49) exceeded the US OSHA EL.

The supervisor in TRS1 (W1) was the only worker sampled who was not exposed to asbestos concentrations above the US OSHA or Colombian standards. This could be explained because this worker rarely manipulated clutch facings, and during sampling Days 1 and 3 did not conduct any manipulation activity. However, personal samples of W1 indicate exposure to asbestos fibers. This is important because even at concentrations in compliance with the regulations, there is a risk of developing asbestos-related diseases (OSHA, 1995). Similarly to W1, other workers and customers that share work areas with riveters may be exposed to asbestos fibers.

Riveter 3 in TRS2 had two samples that exceeded the US OSHA EL. R3 also had the highest 8-h TWA PCME asbestos concentrations among all workers sampled, exceeding the US OSHA PEL and Colombian PLVc in 2 of the 5 days sampled. There are some potential explanations for this. First, based on the activity diaries filled during sampling campaigns, R3 frequently rubbed one clutch facing against the other to eliminate debris, and this activity was often performed close to his respiratory zone. In contrast, riveters in TRS1 used sand paper for this task, and in only one occasion during the sampling campaign, one worker in TRS1 (i.e. R1) rubbed clutch facings (i.e. sample R1 Day2 ST2, in Supplementary Table S1, available at *Annals of Occupational Hygiene* online). Second, cleaning activities of the MA were uncommon in TRS2, and old clutch facings and damaged clutch discs were disposed on the floor. Thus, asbestos fibers could be resuspended, creating an additional source of exposure. Finally, TRS2 was a small shop, with a smaller MA and a lower ceiling in comparison to TRS1. Thus, ventilation conditions were worst in TRS2.

There were two 30-min short-term personal samples collected during the manipulation activities of clutch facings that the riveters reported as asbestos free (i.e. R2 Day3 ST10 and W1 Day2 ST2, in Supplementary Table S1, available at *Annals of Occupational Hygiene* online), and no other activity was performed during these sampling windows. However, these samples had asbestos fibers. This phenomenon was also described in similar studies of brake mechanics in Bogotá (Cely-García *et al.*, 2012, 2014). As it was explained by Cely-García *et al.*, the manipulation equipment may have been contaminated with asbestos fibers during previous manipulation activities, and fibers may have been re-suspended. Another potential explanation was that although riveters reported clutch facings as asbestos free, they might have contained asbestos.

Area samples collected in both shops suggest that other workers not involved in the manipulation activities may be exposed to asbestos fibers. One short-term area sample collected at 2 m from the manipulation equipment was above the personal sample collected on the riveter performing the manipulation. However, the concentrations of both samples were similar (Personal sample R3 Day2 ST2 = 1.653 f cm^{-3}, area sample A2 Day2 ST2 =1.715 f cm^{-3}). These samples were collected while the riveter (R3) was cutting the edges of two clutch facings, and then sanding and grinding them. Because of the location of the door in the TRS (Fig. 1), one potential explanation for this result is that the wind may have blown the fibers away from the riveter toward the sampling equipment.

Workers in shops sampled occasionally used personal protection equipment (PPE) not designed for asbestos protection (i.e. filtering face piece respirators and clothes). The TRS also lacked adequate ventilation systems. TRS2 did not have any ventilation system, and the extraction hood of TRS1 was operated in rare occasions. Moreover, PPE is at the bottom in the hierarchy of occupational control options, and other alternatives, such as source interventions, should be prioritized when trying to reduce the risks of these workers.

From an industrial hygiene perspective, the best option to eliminate the risk of asbestos exposure among transmission mechanics would be to produce asbestos free clutch facings. Another, less desirable option, would be to commercialize ready to install asbestos-containing clutch disks; in TRS2 a clutch disk ready to install was used in one occasion, which did not require any manipulation.

Recognizing that more studies are needed to improve our understanding of asbestos exposures among mechanics that manipulate asbestos containing products, the results for transmission mechanics observed in the current study suggest that they experience higher exposures than passenger vehicle brake mechanics (Cely-García *et al.*, 2012, 2014). In comparison to heavy vehicle brake mechanics, asbestos exposures seem to be similar.

The findings of this study confirm the importance of being cautious when translating the results of occupational studies from high income to low- and middle-income countries. The working conditions, characteristics of the products used, tasks performed by workers, workers training, and the enforcement of regulations to protect workers may have major differences between countries, even when comparing the same occupations.

CONCLUSIONS

Although the workers in the TRS sampled reported that the number of clutch facings manipulations has decreased over time, the exposure concentrations found are high. Thus, this group of transmission mechanics is at excess risk of developing asbestos-related diseases. Furthermore, workers that do not manipulate clutch facings may be exposed to high asbestos concentrations in the workplace. The adverse working conditions of riveters, the need to manipulate asbestos containing clutch facings because they are sold separated from the clutch plate, the lack of training on the risks resulting from working with asbestos-containing products, and the absence of proper engineering controls and PPE, raises serious concerns about the potential implications that all these factors may have on the respiratory health of these workers. Similarly to what we have found in Colombia, workers in other low- and middle-income countries may be experiencing unacceptable occupational risks resulting from asbestos exposure. Thus, it is important to expand our knowledge regarding the risks resulting from the continuous use of asbestos containing products worldwide. The authors recommend that the health, environmental, and labor authorities in Colombia should consider requiring, as a transitory provision, preassembled asbestos-containing friction products when asbestos-containing products are used. The authors strongly recommend that the production and use of asbestos-containing products in the country should be severely restricted or banned.

FUNDING

The financial support was provided by the Department of Civil and Environmental Engineering of Universidad de los Andes for the development of this study.

ACKNOWLEDGMENTS

The authors thank Forensic Analytical Laboratories, Inc., for the analysis of the samples. The authors also thank the workers that participated in the study, and the owners of the BRS that gave us permission to conduct the sampling campaigns on their premises.
The authors have no conflict-of-interest to declare.

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