

Past exposures to airborne fibers and other potential risk factors in the European man-made mineral fiber production industry

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CHERRIE J, DODGSON J. Past exposures to airborne fibers and other potential risk factors in the European man-made mineral fiber production industry. *Scand J Work Environ Health* 12 (1986): suppl 1, 26—33. A historical environmental investigation was undertaken in European man-made mineral fiber factories (MMMF). The aim was to assess past exposures to MMMF and other environmental risk factors (asbestos, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, formaldehyde, and arsenic). A self-administered questionnaire completed by each plant management and an interview of the respondents were used. Addition of oil to the MMMF, change in the nominal fiber size of the bulk MMMF, and elimination of early discontinuous production techniques were identified as principal changes. The absence of oil, small nominal size, and labor-intensive production have been judged to be associated with higher airborne fiber levels. It was concluded that for epidemiologic purposes the subdivision of the history of each plant into an early, intermediate, and late technological phase based on the aforementioned changes would be appropriate. Corresponding time periods were identified for asbestos usage, use of bitumen as a binder, and production of slag wool. Two factories were singled out for specific attention: one where asbestos was used in calcium silicate brick production and one where olivine, used as a raw material, may have been contaminated with natural mineral fibers and where the production process would have exposed workers to coal-tar pitch volatiles.

Key terms: arsenic, asbestos, formaldehyde, glass wool, mineral wool, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, rock wool.

The previous paper in this issue (4) summarizes the measurements of respirable fiber concentrations in mineral-wool production plants. These measurements were obtained in 1977—1980 from environmental investigations made by the Institute of Occupational Medicine in Edinburgh. Prior to this time few monitoring data existed on which to base estimates of historical exposure to airborne fibers.

The conditions in the factories are known to have changed since mineral-wool production first started. The product has been modified to improve the insulation properties. Automation has progressively been introduced into the processes. And engineering controls have been installed at dust emission sources. All of these changes will have altered the airborne fiber levels to which workers are exposed.

In addition to the prime exposure to airborne man-made mineral fibers (MMMF), other pollutants known or suspected to be carcinogens (asbestos, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, formaldehyde, arsenic) have been present in the work environment. The usage of these materials mainly occurred before the recent environmental surveys, and hence no data exist to quantify the level of exposure to these pollutants.

This paper describes a historical environmental investigation undertaken in the 13 factories included in the epidemiologic study carried out by the International Agency for Research on Cancer (IARC), Lyon. The aims of the work were (i) to document the technical history of the plants to facilitate the estimation of past fiber concentrations and (ii) to provide a preliminary assessment of environmental exposures to potential risk factors other than MMMF in the factories.

Methods

Information about the technical history of each factory was obtained from a self-administered questionnaire followed by an interview of plant personnel.

Considerable care was taken in the design of the questionnaire so that experienced plant managers could provide information relevant to factors likely to affect fiber exposure or exposure to other potential risk factors. A list of factors relevant to changes in fiber exposure are shown in table 1, and the basis for their choice is given in a report by Cherrie & Dodgson (3). After discussions with industry representatives a draft questionnaire was tested at a factory in the United Kingdom, and, following further comments from the industry, a final version was produced (3).

An introductory meeting was organized, and industry representatives from all of the factories included in the epidemiologic study were invited to attend. At this meeting the purpose of the historical environ-

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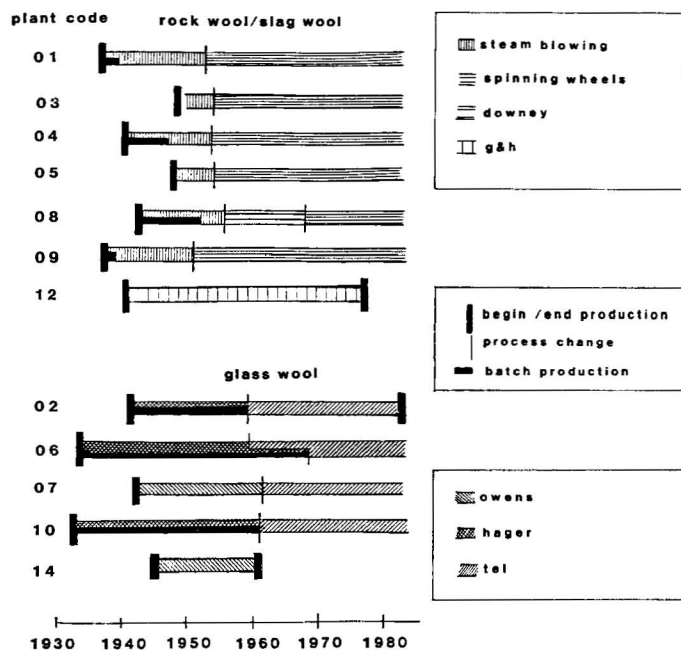


Figure 1. Production process type for the rock- and glass-wool factories. (g & h = Grunzweig & Hartmann, tel = process from the Laboratoire Experimentale Thermique)

mental investigation was outlined, the format of the questionnaire was presented, and a recommended method for completion was suggested.

After the meeting, the questionnaire was circulated to the management of each plant with the request that it be completed, where possible, with the assistance of workers who had experience from the whole period during which the factory had operated. On completion of the questionnaire, the persons who provided the information were interviewed by representatives from the the Edinburgh Institute of Occupational Medicine and IARC, and by national collaborators with IARC. At this interview additional information on various chemical and physical agents present in the workplace was obtained.

Summary of the technical history of the factories

Figure 1 summarizes the major changes in the production process at the rock-wool/slag-wool and glass-wool factories. This figure does not include the glass continuous-fiber production plants where the drawing process has remained essentially unchanged and MMMF exposures are very low (<0.01 fibers/ml).

The early production methods for glass and mineral wools began with relatively crude processes in which the prime technique used to generate fibers was either blowing steam or compressed air through a stream of molten glass or rock (ie, the Owens process or the steam blowing process) or using centrifugal force when molten glass was allowed to fall onto the surface of a spinning refractory disc (ie, the Hager process) (9).

Labor-intensive batch (discontinuous) production techniques were initially used at four of the rock-

Table 1. Factors influencing airborne fiber concentrations.

Factor	Reference
Fiber size in the bulk product	Esmen et al (7)
Binder and oil content	Schneider & Smith (14)
Type of process	.
Size of building	.
Production rate	Esmen (6)
Ventilation	.
Use of respirators	.
Cleaning of workplace	.
Secondary production process	.

wool/slag-wool plants for periods between one and seven years.² The three glass-wool factories operating the Hager process had more extensive periods of batch production, ranging from 18 to 34 years.

Figures 2 and 3 illustrate the conditions in two factories operating batch production regimens.

During the 1950s most of the factories adopted production techniques similar to those currently used, ie, the spinning wheel process for rock wool and the TEL (derived from "laboratoire experimentale thermique") process for glass wool.

² Following the original publication of this historical environmental investigation, some of the factory managements provided information suggesting that the original estimates of the duration of batch production techniques might be incorrect.

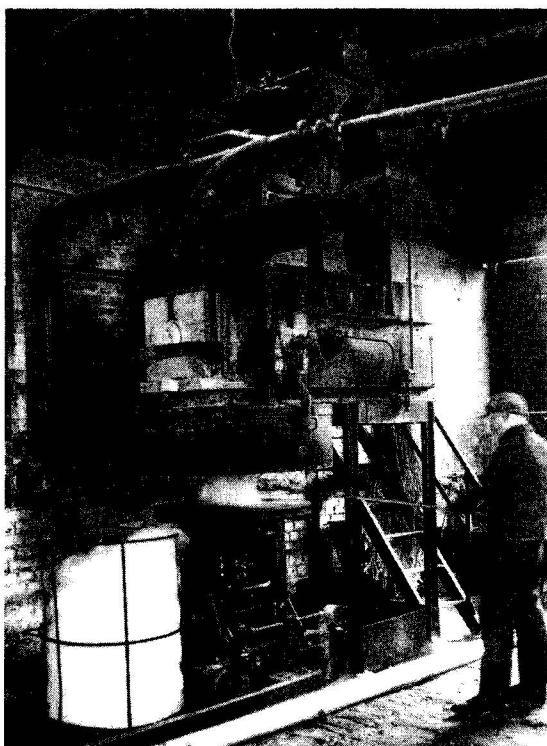


Figure 2. The Hager process for manufacturing glass wool — Fiberization process in the picture on the left and the manufacture of stitched mats on the right. (Photographs from a German factory in about 1938, not included in the present study — courtesy of Dr Fourtak, Grunzweig & Hartmann und Glasfaser Ag)

Exposures to airborne fibers

In a review of published data the two factors identified by Cherrie & Dodgson (3) as most important to fiber emission levels from MMMF were nominal fiber size (ie, length-weighted average fiber diameter in the bulk product) and the addition of oil to MMMF wool products. It was estimated that both factors could produce differences of approximately ten times.

Changes in nominal fiber size have generally been associated with changes in the production process. The range of nominal fiber diameters from current processes was small and similar in both the rock-wool and glass-wool factories, 3 to 6 μm and 5 to 7 μm , respectively. The earlier rock-wool/slag-wool steam blowing process gave nominal diameters similar to the present day values, but the early glass-wool processes produced larger nominal fiber diameters (approximately 10–25 μm). According to the work of Esmen et al (7) these changes would have tended to result in lower airborne fiber concentrations in the early glass-wool plants than in current production processes but would have had little effect on rock-wool/slag-wool production.

The year of addition of oil to MMMF wool products is shown in figure 4. In this diagram the width of the bar for each factory is approximately proportional to the percentage of the production to which oil was added. The majority of rock-wool plants has added oil from an early stage in the production history, the

largest gap being 8 years. Only one of the glass-wool plants (plant 10) added oil to a significant proportion of its total production before 1960.

On the basis of the work of Schneider & Smith (14) and other corroborative evidence, the period with no oil added has been estimated to give rise to higher fiber levels.

None of the other factors investigated (ie, size of building, production rate, ventilation, etc) were judged to have contributed to the same order of magnitude as the addition of oil, nominal fiber size, or batch production.

Other environmental exposures

Asbestos

Asbestos has been used, in some form, in all of the factories. The primary uses have been personal protective equipment, such as gloves, aprons, etc, and as thermal insulation. Four factories had used small quantities of asbestos products (probably chrysotile) in secondary production (plants 01, 02, 10, and 12).

Plant 01 used asbestos cement slabs in one process between 1962 and 1982. Two workers were employed in cutting the asbestos cement sheets, and a further 50 workers were employed in this area. During 1954 asbestos was used as a constituent in an experimental



Figure 3. The rock-wool/slag-wool steam blowing process — Fiberization process in the upper picture on the left, the inside of a blowing chamber (worker removing man-made mineral fibers) in the lower picture on the left, and the manufacture of wire mats in the picture on the right (courtesy of the management of plant 01)

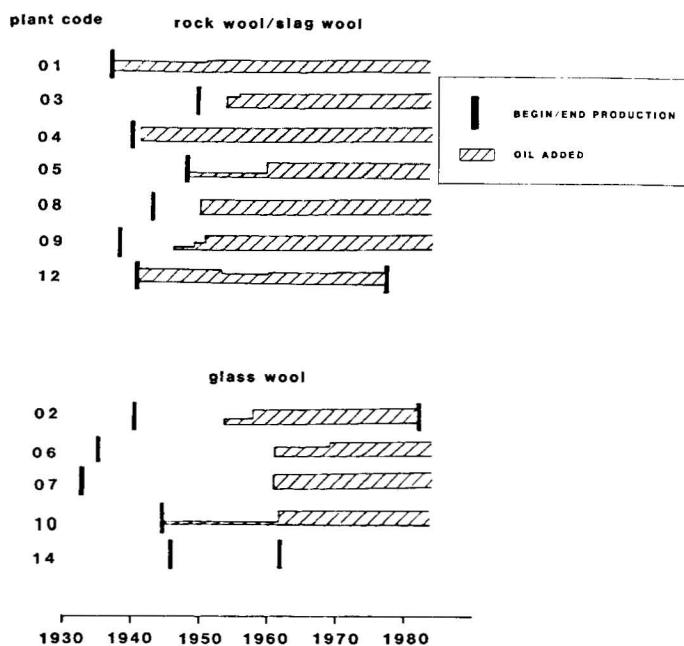


Figure 4. Addition of oil to man-made mineral fibers. The width of the bars is proportional to the quantity of oil added.

rock-wool mortar. This work was reported as being very dusty.

In plant 02 asbestos cloth and yarn were used to make mattresses between 1946 and 1948. Two workers were employed in this process.

Plant 10 used asbestos stitching yarn in making wire mattresses between 1946 and about 1970. Between 1961 and 1962 experiments were undertaken to manufacture a calcium silicate material containing amosite and chrysotile with some crocidolite. In both instances small numbers of workers would have been exposed.

Three processes at plant 12 used asbestos. Between 1941 and approximately 1970 approximately 1 % of all mattresses and stitched quilts made were covered by asbestos cloth, and approximately 10 % were stitched with asbestos yarn. Two or three workers were directly involved in handling asbestos. Asbestos yarn was used in the manufacture of ropes in the early 1950s but was quickly replaced with wire. Between 1962 and 1968 calcium silicate bricks were manufactured. These bricks contained about 4 % chrysotile asbestos, reduced to 1 % after three years. A maximum of 10–20 workers was employed in this process; some would have been involved in the manual mixing of raw materials — including asbestos.

One of the factories, plant 04, used olivine as a raw material between 1941 and 1967. It is probable that this material was contaminated with acicular mineral fibers with a composition similar to tremolite. The mean level of these fibers in an olivine quarry, evaluated by phase contrast optical microscopy, has been found to be approximately 0.1 fibers/ml (Gylseth, personal communication).

Polycyclic aromatic hydrocarbons

Bitumen had been used at three rock-wool plants and one glass-wool plant as a binder for the MMMF. There had also been some limited use in secondary production as a binder or adhesive. No information was available concerning the exposure levels of polycyclic aromatic hydrocarbons (PAH) from these processes although the available evidence would suggest that they would be very low (5, 10).

One factory, plant 12, used coal tar pitch between 1878 and 1970 in a cork production process. The level of PAH would probably have been relatively high in this process. Between 30 and 120 workers were employed in this process, which was not located in the same building as the MMMF production. Every effort has been made to exclude these workers from the epidemiologic study cohort.

One factory, plant 04, used an electric furnace similar to the Soderberg aluminum smelting process. In this system a paste made from coke and coal-tar pitch was utilized in the electrode. This type of electrode is known to generate very high levels of PAH (1). This furnace type operated from the start of production to 1967.

Workers exposed to coal-tar pitch volatiles show increased mortality from bladder cancer and lung cancer (8, 12).

Mineral oil has been extensively used as an additive to MMMF in all of the insulation wool factories, as previously described. However no information is available concerning the levels of oil mist in the factories or the levels of PAH present.

Furnace combustion products have been found to contain varying levels of PAH depending on the type of fuel and method of combustion. In most cases these products would have been ducted out of the work-room.

It has been suggested that in the area close to the furnace in rock-wool factories the environmental conditions are similar to those found in an “iron foundry” (Kamstrup, personal communication). In particular it has been implied that workers were exposed to high levels of PAH from smoke and combustion gases emanating from the furnace. In our opinion the levels of PAH in the early phase of the rock-wool industry are unlikely to have been as high as encountered in a foundry. In a foundry the high levels of PAH are considered to be caused by the action of hot metal on coal-tar pitch or other organics included in the molding material. Levels of benzo(a)pyrene [B(a)P] in excess of 1 $\mu\text{g}/\text{m}^3$ have been measured during these processes. The PAH levels in the early phase of the rock-wool industry may have been similar to those found generally in the iron and steel industries, where B(a)P levels are generally reported to be less than 1 $\mu\text{g}/\text{m}^3$ (10).

Polychlorinated biphenyls

One factory, plant 04, reported that transformer oils, containing polychlorinated biphenyls, were used occasionally as a substitute for mineral oils. This substitution occurred between about 1940 and the early 1950s, when oil was difficult to obtain. A second factory, plant 12, suggested that transformer oils may have been used, but this possibility could not be confirmed.

Formaldehyde

Formaldehyde has been used in all of the glass- and rock-wool factories in the production of resin binders. Exposure levels were probably high in the initial period of use. Most plants reported that the odor of formaldehyde was frequently detected (ie, >0.5 ppm), and, occasionally, it was reported as causing severe irritation (about 5–10 ppm). In one factory producing glass wool, plant 02, measurements made of formaldehyde during 1977 showed that next to the curing ovens the concentration ranged from 0 to 5 ppm. Most factories reported that the concentrations of formaldehyde were currently less than the occupational exposure limit of 2 ppm.

Slag

Three factories (plants 01, 08, and 09) have had significant periods in which either slag wool or mixed rock/slag wool were produced. Two of the remaining four factories used slag as an additive to rock wool in some short-term experiments. The majority of material used was iron slag, some lead and copper slag being used occasionally.

Copper slags were used periodically between 1940 and 1944 at plant 01. It is possible that these slags may have contained substantial quantities of inorganic arsenic as an impurity. Arsenic trioxide has been implicated as a cause of lung cancer in a variety of occupations, including copper smelting.

Discussion

No direct measures of airborne fiber concentrations exist in the majority of the factories included in the epidemiologic study prior to the surveys made by the Edinburgh Institute of Occupational Medicine. The interpretation of the measurements which do exist is complicated by variations in sampling or analytical procedures or by the errors implicit in fiber number assessments. From the existing data it is not possible to estimate historical airborne fiber levels reliably. However, further investigations of dust emissions from old and current bulk MMMF products are in progress. It is hoped that the results of these studies will help quantify the relationship between airborne fiber levels, nominal fiber size, and oil content. These data may contribute towards assisting with the estimation of past airborne fiber concentrations.

A number of factors, such as the addition of oil to the product, production technique, ventilation, etc, have been identified as potentially affecting airborne fiber levels. The information on the various factors indicates that the addition of oil, nominal fiber size, and production technique probably provide the major contribution to change.

A review of the published data (3) has shown that the effect of adding oil to MMMF insulation wool reduces the fiber emission from the product by about ten times or more, and a reduction in the nominal diameter could produce an increase in fiber emission by up to ten times.

The effect of changing from discontinuous batch production to a continuous production regimen is unclear. The early processes were labor intensive, as illustrated in figures 2 and 3, producing relatively small quantities of fiber. After the introduction of a conveyor system to transport fiber from the production chamber, smaller numbers of workers were involved in handling MMMF although there was an increase in the production rate. The change in fiber concentration was probably of a lesser magnitude than the previously discussed factors.

For the purposes of epidemiologic analysis the production history of each factory has been classified into the following two distinct technological phases: (i) an early phase where a batch production system was in use and/or no oil was added to the MMMF during production and (ii) a late phase where modern production techniques were used to manufacture MMMF with oil added. A third phase, intermediate between the early and late phases, was also identified at some plants where a mixture of production types or techniques operated. Table 2 shows these critical dates for each of the factories.

It is judged that the airborne fiber levels during the late technological phase have been relatively stable and reasonably well represented by the current measurements. This conclusion has been tested by a small number of repeat measurements of airborne fiber concentrations made four to seven years after the original survey (2). These measurements showed that the concentrations in the later surveys were generally lower than the original data, although the absolute magnitude of the change was small. In the glass-wool plants the mean concentrations ranged from <0.01 to 0.05 fibers/ml compared with 0.02 to 0.10 fibers/ml during 1977–1980, and current mean concentrations in the rock-wool plants ranged from 0.02 to 0.10 fibers/ml compared with 0.05 to 0.14 fibers/ml originally.

The conditions which occurred in the rock-wool/slag-wool plants in the early phase, ie, no oil added and labor-intensive production techniques, would have produced airborne fiber levels higher than currently experienced, the difference being primarily due to the absence of oil in the product. The estimated fiber concentration would be in excess of ten times higher than in the late technological phase, ie, about 1 fiber/ml, and possibly as high as 10–25 fibers/ml. The latter data have been obtained from samples collected in a modern production plant manufacturing rock wool without the addition of oil or binder (11).

In the early technological phase in the glass-wool plants the effect of a thicker nominal diameter, no oil

Table 2. Critical dates to subdivide plant histories into technological phases.

Plant number	1st date ^a	2nd date ^b
01	1940	1953
02	1959	1959
03	1954	1956
04	1946	1955
05	..	1961
06	1960	1969
07	1961	1961
08	1950	1956
09	1945	1951
10	1945	1968
11	..	..
12	..	..
14	1961	1961

^a No oil and/or batch production prior to this date.

^b After this date conditions similar to present day.

added, and labor-intensive production techniques probably produced airborne fiber levels more similar to the late phase measurement.

The following three principle potential exposures known to be associated with lung cancer have been identified: asbestos, PAH, and metal slags. [For a more complete discussion of these three types of exposures, see the report of Simonato et al (15).]

Asbestos has been used in all of the factories for personal protective equipment such as gloves and aprons and as thermal insulation. There are reports which indicate that measurable concentrations of asbestos can be released during the wearing of asbestos gloves (13). In general the levels are low, the 8-h time-weighted average being less than 1 fiber/ml and the number of persons exposed small.

The application or removal of thermal insulation or gasket materials could potentially give rise to relatively high concentrations of airborne asbestos, but these exposures would be of relatively short duration.

Asbestos materials have additionally been used at four factories, mostly as stitching yarn or cloth. In stitching operations exposure levels were probably low (about < 1.0 fibers/ml); where asbestos cloth has been used in mattress manufacture higher airborne asbestos fiber concentrations could have been experienced (about < 10 fibers/ml). It should be noted that only a small number of workers were directly involved in handling asbestos in these secondary production operations.

In three situations where the handling of loose asbestos fibers occurred (plant 01 — experimental mortar, plant 10 — experimental calcium silicate mixture, and plant 12 — production of calcium silicate bricks), airborne asbestos fiber levels may have been relatively high. In plants 01 and 10 these were experimental tests of short duration with very small numbers of workers involved.

At another plant (plant 04) olivine potentially contaminated with natural mineral fibers was used. The available evidence suggests that fibers found in the olivine used at this factory have a chemical composition similar to tremolite asbestos, with a relatively low aspect ratio (< 10:1). Based on measurements by Gylseth (personal communication), the probable average fiber concentration in the preproduction area would be about 0.1 fibers/ml.

The exposure to PAH from bitumen and mineral oils is considered to have been low. Bitumen does not appear to liberate substantial quantities of PAH, even when heated. Emission of PAH from poorly refined mineral oil would be primarily confined to the period before 1968, when improved refining techniques were introduced. The major source of emission would have been confined to the area close to the curing ovens.

It is expected that high levels of PAH would be present in the effluent gases and particulates from the furnace, particularly from the cupola furnaces used in rock-wool/slag-wool plants. These pollutants would

have been vented out of the factory, although it is likely that in the early production period some leakage into the work area may have occurred. It is judged that in this early period, in rock-wool/slag-wool plants, the levels of PAH may have been moderate, by the definition of Lindstedt & Sollenberg (10) similar to levels generally found in iron and steel industries.

The use of *coal-tar pitch* was mostly confined to one factory, in a non-MMMF process (cork production). Workers in this area would have been exposed to high levels of PAH. Every effort has been made to exclude workers from this area from the epidemiologic study cohort.

Exposure to PAH from coal tar used in the electric furnace at plant 04 would have been high for workers in the furnace area. In this factory the workers rotated jobs from MMMF production to work in the furnace area, and so most would have had some periodic exposure to these conditions.

Possible exposure to *arsenic* from copper slags occurred for a maximum of four years' duration in the preproduction area of one factory (plant 01). No details are available on the extent of the usage of copper slag or on the exposure levels during use.

Conclusion

The agents which could potentially present a risk for lung cancer in the epidemiologic study were the use of asbestos at one factory (plant 12), calcium silicate brick production, and the contamination of olivine and exposure to coal-tar pitch volatiles at a second factory (plant 04).

Changes in the nominal fiber size and the addition of oil to MMMF products have been identified as important in relation to dust emission levels. In addition the batch production methods used in the early years at some of the plants have been identified as being associated with a greater degree of manual handling and hence probably higher airborne fiber levels.

It was concluded that it was reasonable to divide each plant history into an early, intermediate, and late technological phase representative of different environmental conditions for epidemiologic investigations (15).

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