British Journal of Industrial Medicine 1983;**40**:8–12

Environmental history of a factory producing friction material

J W SKIDMORE AND B L DUFFICY

From the MRC Pneumoconiosis Unit, Llandough Hospital, Penarth, S Glamorgan, and Ferodo Limited, Chapel-en-le-frith, Stockport, UK

ABSTRACT The fibre concentrations generated during the production of friction materials, incorporating asbestos, over the past 60 years have been studied to provide cumulative dust exposure data for a mortality study of the work-force. Chrysotile has been used almost exclusively during this period. The measurements made routinely by the factory staff provided information from 1950 onwards; concentrations for earlier years were derived from simulation studies using original materials, machines, and methods. These have shown that while high concentrations prevailed in the earliest years dust suppression measures initiated in 1931, and other factors, reduced the time-weighted average concentrations to moderate levels. There were two four-year periods when the production of brake blocks incorporating crocidolite occupied a well-defined area of the factory. The simulation of this production was not permissible, but the employees concerned could be identified.

A study of a factory that for many years has been using mainly one type of asbestos was considered useful both in general terms and also as a contribution to the resolution of suggested differences between the carcinogenic properties of the various types of asbestos if adequate corresponding mortality and environmental data could be obtained. Good records have been maintained by the personnel department identifying all employees in post in 1941 and thereafter with sufficient detail to obtain mortality data from the national registers. The records also contain details of the work history of the individual. Environmental measurements have been made only since 1968. Since many of the machines in use in the earliest years have been successfully maintained, with dated records of exhaust ventilation modifications, and many products with the older formulations are still being produced, simulation of earlier working conditions was considered feasible. Measurements of the clouds produced could be made using modern methods to provide the environmental data required for the study.

Factory development

The factory has been producing friction materials since the turn of the century when cotton cloth and oil-based impregnants were used as the basic materials. Woven chrysotile brought into the factory in 1910 as an alternative to the cotton cloth had virtually supplanted it by 1920. Loose asbestos fibre was introduced into the factory two years later when a patent was granted on a method of brake-block making, using loose asbestos and resin cast into a mould. Since that time the production of materials containing either woven or loose fibre has continued. Brake and clutch linings and floor coverings are produced using similar procedures. Woven asbestos is received in roll or coil form and is stored until required. On demand the rolls are calendered and cut before passing through a resin bath after which the impregnated material is formed and heat treated. Subsequent machining may include any selection of edge and surface grinding, sawing, turning, boring, and drilling operations before passing through stencilling and examination. The finished product then passes through to the despatch area.

Bales of asbestos fibre are similarly received, stored, and issued on demand. After opening and weighing, the fibre may be either dry mixed with resin and additives in a mould then pressed, baked, and machined, or mixed with resin plus additive to produce a dough that is subsequently rolled, cut, baked, and machined.

Production began in an old mill building but was transferred in 1916 to a purpose-built factory block.

Received 23 June 1982
Accepted 3 August 1982

A "long bench" method of working was used in which all the stages were performed in a small area, and all the workers were exposed to similar fibre cloud concentrations. Dust suppression, beyond the "good housekeeping" required for efficient production was non-existent. This method continued until 1929 when two new factory blocks were built to meet increasing demand for the products. These new blocks were extended over the next 15 years, providing a fivefold increase in the production floor area. The Asbestos Regulations (1931)[1] were fully implemented throughout the factory by 1933. These regulations required the use of respirators when handling dry asbestos and the application of exhaust ventilation to some machining operations. Notable exceptions to the requirements were short-term drilling operations and the turning, boring, and shaping of concentric products. No further dust suppression measures were introduced until about 1949 when some general improvements were initiated, including product cleaning and the application of exhaust ventilation to machines not specified in the Asbestos Regulations. To provide space for further expansion the manufacture of materials incorporating woven materials was transferred to a new factory in 1960. In anticipation of the imposition of new threshold limit values for asbestos an environmental survey of the factory was made in the period 1967–9 to define those areas requiring further dust suppression. Subsequently, considerable improvements were made through the factory including the wrapping of incoming asbestos supplies, raising the efficiency of some exhaust ventilation, extending the use of vacuum cleaners, and modifying some of the working practices.

Chrysotile has been the preferred type of asbestos for technical reasons, and African and Canadian chrysotiles, supplied by a sister company, have been used almost exclusively throughout the life of the factory. Exceptionally, two orders specifying the use of crocidolite asbestos in railway brake blocks were received in 1929 and 1939. The execution of each order occupied one small area of the factory for four years. The only other use of crocidolite has been in small research projects. Anthophyllite asbestos, received as a millboard, has also been used in small quantities.

The environmental history of the factory consists of four periods:

(1) Pre-1931 before the Asbestos Regulations and when all operations were carried out in one open plan area.

(2) 1932–50, when exhaust ventilation was applied to many machining operations and larger premises provided for greater separation between the stages of production.

(3) 1951–69, a period of gradual improvement including product cleaning and the application of exhaust ventilation to machines not included in the Asbestos Regulations.

(4) 1970–9, after the introduction of the 2 fibres/ml (2 f/ml) TLV.

Environmental measurements

Few measurements of airborne fibre related to the first two periods. Measurements made during 1968–9 could be considered to relate to the third period, since there had been few changes in this period. Exceptionally, the application of exhaust ventilation to the boring and turning of concentric materials in 1963 and an oil mist treatment to woven asbestos received after 1958 was noted. Adequate measurements were obtained during the fourth period both by factory staff and government inspectors. Realistic simulation of the earlier conditions was, therefore, necessary to determine the fibre concentrations to which the employees had been exposed. The essential requirements for this included supplies of basic materials and the original machines in appropriate proximity which could be operated according to the practices of the period. Many of the old formulations are currently used, and the basic materials were generally readily available. Original machines were also available together with details of the application of exhaust ventilation, and an experimental workshop provided a suitable site for assembling a group of the smaller machines in appropriate proximity. During the period being studied these machines were powered by line shaft belts that created localised air currents. This power system not being available, small electric fans were used to recreate similar air movements. Very importantly, the attitudes and methods of working were obtained by including several long-service employees, who volunteered their services, as operatives. Recreating the clouds associated with the largest machines and presses were necessarily obtained in situ, after modification, and those applying to the mixing of larger quantities of asbestos were made in an area similar to that previously used. It was not permissible to reproduce the clouds associated with the use of crocidolite in the production of railway blocks. The simulations took place during factory shut-down periods at weekends, and the operatives wore approved protective clothing and respirators. To provide time-weighted average concentrations the simulations extended over periods of four to five hours. Personal samplers were used with the sampling head mounted in the breathing zone of the operatives and servicemen. Static samplers were also mounted at head height nearby to provide information with regard to the general atmospheric contamination. As for the more recent measurements made by the factory personnel, the samples were evaluated as in the method described in the ARC technical note 1,[2] using phase-contrast microscopy incorporating an eyepiece graticule, counting fibres longer than 5 μm.

The samples obtained by factory personnel during the period 1968–74 were evaluated without the use of an eyepiece graticule counting all fibres in the field of view. The use of an eyepiece graticule followed observations by Beckett *et al*[3] that full field counting resulted in underestimations of fibre concentrations. Checks made at the time of changeover confirmed that the full field counting had resulted in underestimates of about 15%. The concentrations obtained during 1968–9 and later were accordingly adjusted.

Results

The clouds contained many more irregular shaped particles than fibres. While dried resin particles were apparent in clouds produced after impregnation, there was no evidence of any resin coating on the airborne fibres even when examined with the transmission electron microscope. The fibres were highly respirable, most having diameters smaller than 1 μm and more than 90% of the fibres longer than 5 μm were shorter than 30 μm. A typical length distribution (table 1) is similar to that obtained by Gibbs and Hwang[4] from clouds produced in chrysotile mining and milling operations. Since it was not possible to reproduce every operation, the simulations made were selected to provide general levels of cloud concentration in the various stages of the production. In the earlier periods most of the products incorporated woven asbestos, and the simulations included the handling and calendering of rolls and the drilling, boring, sawing, and grinding of products with and without exhaust ventilation. The simulations for the products incorporating loose fibre included bag opening, weighing and mixing, mould filling and pressing, and subsequent machining. These measurements were supplemented by those obtained later for processes such as impregnation and forming that had not changed. The machining operations without exhaust ventilation generated high concentrations, in particular the grinding and finishing produced fibre concentrations ranging up to 50 f/ml. Concentrations exceeding 20 f/ml were also obtained during the bag opening and mixing of loose fibre and the removal of debris from floor and work surfaces. The varied siting and the close proximity of the operations indicated a concentration in excess of 20 f/ml over the whole production area during the first period.

The clouds to which the employees were exposed were greatly reduced at the beginning of the second period as a result of the application of exhaust ventilation to some of the machining processes and also of the partial departmentalism that took place with the expansion of the works. The receiving and storage department was separated from the later processing. In this department the clouds associated with the receipt and storage of asbestos fibre were higher than those associated with handling the rolls of woven asbestos because of spillages from damaged bags. This difference also applied to a greater extent in the preparatory stage, when larger quantities of asbestos fibre were weighed and mixed. The application of exhaust ventilation to grinding and finishing machines generally reduced the fibre concentrations to under 10 f/ml, but higher concentrations were observed when the largest components were being processed. Drilling, boring, turning, and sawing without exhaust ventilation generated clouds containing up to 8 f/ml and similar concentrations were generated by the dispersion of dust on the products during the examination and stencilling stages. This dust created stencilling problems which were overcome at the end of this period by vacuum cleaning the product after machining, which halved the concentration to which the examiners and stencillers were exposed. The application of exhaust ventilation to other machining operations and improvements, in addition to that already applied to the grinding operations, similarly reduced these clouds during the third period.

After the 1968–9 survey, extensive improvements in dust control were introduced to achieve compliance with the proposed threshold limit value. These included the more effective wrapping of incoming supplies, ventilated enclosures for weighing and mixing fibre, modifications to presses, and the upgrading of exhaust ventilation generally and its application to the examination and stencilling benches. As a result successful control of the airborne dust was achieved. Surveys during this period have indicated almost 100% compliance, and the rare

Table 1 *Length distribution of airborne fibres longer than 5 μm*

	Size range (μm)						
	5–10	*11–20*	*21–30*	*31–40*	*41–50*	*51–100*	*>100*
Frequency %	58·0	30·5	5·2	2·2	2·4	1·3	0·5

Table 2 *Average concentrations of chrysotile fibres from loose fibre products (fibres/ml length >5μm)*

Period	*Storage/ distribution*	*Preparation*	*Impregnation/ forming*	*Grinding*	*Drilling, boring, turning*	*Inspection stencilling*	*Packing despatch*	*Office/ laboratory*
Pre-1931	>20	>20	>20	>20	>20	>20	>20	10–20
1932–50	1–2	1–2	1–2	5–10	2–5	2–5	1–2	<0·5
1951–69	1–2	1–2	1–2	2–5	1–2	2–5	1–2	<0·5
1970–9	0·5–1	0·5–1	1–2	1–2	1–2	1–2	1–2	<0·5

exceptions have generally been found to result from individual working methods. The variability of fibre concentrations associated with individual methods of working and the product size required that the average fibre concentrations be expressed in ranges; these are given in tables 2 and 3 for the main steps in the production process. The concentrations allocated to office and laboratory staff during the first two periods are estimates based on the location of the offices and time spent in the production areas.

The fibre concentrations generated in the production of the railway blocks incorporating crocidolite were not measured. The blocks were produced by mixing crocidolite and resin in a mould, pressing, and baking. Using chrysotile this method produced fibre clouds containing up to 5 f/ml and subsequent grinding produced clouds containing up to 10 f/ml. The greater dispersive properties of crocidolite fibres would be expected to provide appreciably higher concentrations in the working area.

Discussion

While fibre concentrations before 1931 were high, moderate concentrations have been produced since then. The standards of housekeeping have been high, and the desire for tidiness has prompted efforts to reduce the level of dust perhaps at a lower level than would have occurred with clouds containing a higher proportion of fine fibres. It may be fortuitous that this desire for tidiness also maintained a ban on smoking in the production areas from the earliest days up to 1950, when refreshment areas were provided in which smoking was allowed. The measurements obtained, together with the detailed occupational histories, have provided the necessary information for calculating the cumulative exposure to chrysotile asbestos. While this information is not available for the exposure to crocidolite, the personal records do provide the information identifying the employees actively concerned in its use, and also those working in the vicinity who would have had a reduced exposure. This has proved important in determining the aetiology of most of the mesotheliomas observed in the mortality studies.[5,6]

In recent years the use of properly fitted respirators in extreme conditions—for example, dust plant maintenance or accidental spillages—would be accepted as essential by the work-force. A consensus of long-term employees was that this attitude was very much less general during our second period, and their regular use by operatives in the fibre preparation department should not be assumed. Except for the above examples it has not been necessary for any employee to use a respirator in the factory during the past decade.

We thank Ferodo Ltd, who most generously provided the facilities for this study. We are also indebted to the laboratory management and staff, particularly Mr T Jacques, Mr H Martin, and the late Mr C Niven, who have been responsible for the dust cloud measurements at the factory for many years. The splendid co-operation of the operatives who contributed to the simulation studies was very much appreciated.

References

1 *Asbestos Industry Regulations: Statutory Rules and Orders, 1931.* No 1140. London: HMSO, 1931.
2 Asbestos Research Council. *The measurement of airborne asbestos by the membrane filter method.* Rochdale, Lancs: ARC, 1971. (Technical note 1.) (ARC, PO Box 40, Rochdale, Lancs.)
3 Beckett ST, Hey RK, Hirst R, *et al.* A comparison of airborne

Table 3 *Average concentrations of chrysotile fibres from woven asbestos products (fibres/ml length >5μm)*

Period	*Storage/ distribution*	*Preparation*	*Impregnation/ forming*	*Grinding*	*Drilling, boring, turning*	*Inspection stencilling*	*Packing despatch*	*Office/ laboratory*
Pre-1931	>20	>20	>20	>20	>20	>20	>20	10–20
1932–50	2–5	10–20	2–5	5–10	2–5	2–5	1–2	<0·5
1951–69	2–5	2–5	1–2	2–5	1–2	1–2	0·5–1	<0·5
1970–9	0·5–1	1–2	0·5–1	0·5–1	1–2	0·5–1	<0·5	<0·5

asbestos fibre counting with and without an eyepiece graticule. *Ann Occup Hyg* 1976;**19**:69–76.

4 Gibbs GW, Hwang CY. Dimensions of airborne fibres. In: Wagner JC, ed. *Biological effects of mineral fibres*. Lyon: International Agency for Research into Cancer, 1980: 69–77. (Scientific publication No 30.)

5 Newhouse ML, Berry G, Skidmore JW. A mortality study of workers manufacturing friction materials with chrysotile asbestos. In: Walton WH, ed. *Inhaled Particles V*. Oxford: Pergamon, 1982: 889–909.

6 Berry G, Newhouse ML. Mortality of workers manufacturing friction materials. *Br J Ind Med* 1983;**40**:1–7.