T I. Occurrence of Pulmonary Fibrosis and other Pulmonary Affections in Asbestos Workers

T II. Processes giving rise to dust and methods for its suppression

BY

E. R. A. MEREWETHER, M.D.

H.M. Medical Inspector of Factories

AND

C. W. PRICE

H.M. Engineering Inspector of Factories

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REPORT ON EFFECTS OF ASBESTOS DUST ON THE LUNGS

and

DUST SUPPRESSION IN THE ASBESTOS INDUSTRY

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This Report was laid before Parliament on the 24th March, 1930, but has not been published as a Command Paper.

The Right Hon. J. R. Clynes, M.P.,
His Majesty's Secretary of State
for the Home Department.

Home Office,
17th March, 1930.

Sir,

I submit herewith a Report by Dr. E. R. A. Merewether and Mr. C. W. Price on their inquiries into the health conditions of the asbestos industry. Dr. Merewether's investigations on the medical side are of great scientific value. They establish the facts that the inhalation of asbestos dust over a period of years results in the development of a serious type of fibrosis of the lungs, that the development of the disease varies in direct proportion to the length of the exposure to dust, and that susceptibility to the disease is not affected either by age or sex.

The remedy for these conditions is to be found, as in the case of so many industrial diseases, in the suppression of dust. The second part of the Report indicates that this point has only recently been appreciated. In the non-textile section of the industry, no serious difficulties arise as regards the application of exhaust ventilation. For the textile section, it is evident that a good deal of experimental work will have to be carried out before completely successful ventilating appliances are evolved effectively to remove all the dust.

I have the honour to be,

Sir,

Your obedient Servant,

GERALD BELLHOUSE,

H.M. Chief Inspector of Factories.

Report on Effects of Asbestos Dust on the Lungs and Dust Suppression in the Asbestos Industry.

PART I.

THE OCCURRENCE OF PULMONARY FIBROSIS AND OTHER PULMONARY AFFECTIONS IN ASBESTOS WORKERS

1.—Introduction.

This Report is based upon the data obtained in an extensive investigation during the years 1928 and 1929. The inquiry was initiated by the Factory Department of the Home Office following the discovery in February, 1928, of a case of non-tubercular fibrosis of the lungs in an asbestos worker, of sufficient severity to necessitate treatment in hospital (Seiler's Case[1]).

Prior to this, this Department had knowledge of only two deaths of asbestos workers, about whom there was expert opinion that the inhalation of asbestos dust had at least contributed to, if not caused, the fatal outcome. The first of these, now referred to as the "Montague Murray Case," occurred in 1900, but all that is known concerning it is contained in the evidence given by Dr. Montague Murray in 1906, before the Departmental Committee on Compensation for Industrial Diseases[2]. In this case post mortem examination confirmed the clinical diagnosis of extensive non-tubercular pulmonary fibrosis. The second (Cooke's Case[3]) occurred in 1924. Here, although Cooke[3] and Stuart McDonald[4] were of the opinion that the lungs showed a progressive dust fibrosis together with a chronic tuberculous infection, the etiological relationship between the inhalation of asbestos dust and fibrosis of the lungs would have been strengthened by the absence of a tuberculous infection.

An early survey of the industry in 1910-11 by the Department did not disclose any evidence of the existence of a serious health hazard in the industry, but some experiments on animals conducted in 1912 by Professor J. M. Beattie of Sheffield University for the Department showed that the inhalation of asbestos dust will cause a mild degree of fibrosis.

When, therefore, investigation of Seiler's Case showed that other industrial and infective causes of fibrosis could be definitely excluded, the necessity of deciding whether the supervention of this disease in an asbestos worker was an exceptional occurrence, or evidence of a grave health risk in the industry, was apparent and the investigation referred to was undertaken.

2.—Effects of Irritant Dust Upon the Lungs.

The most important local effects which may follow the inhalation of dust include pulmonary and bronchial catarrh, asthma, bronchitis, fibrosis of the lungs, and secondary changes, such as emphysema, local or diffuse. These changes in the lungs, which may be looked upon as a measure of the efforts of the living tissues to repel or incarcerate the irritant particles of dust, necessarily cause interference with the general efficiency of the lungs. The impairment of functional capacity may be slight or severe, and temporary or permanent, depending on the variety of dust, and on other factors, such as concentration of dust and length of exposure.

Moreover, individuals whose lungs have been affected as the result of the inhalation of some dusts, show an increased susceptibility to the supervention of respiratory infections, such as tuberculosis or pneumonia.

Fibrosis of the lungs is recognised to be the most important lesion caused by the inhalation of dust, and the proneness of workers with a dust fibrosis to be affected with pulmonary tuberculosis has been shown to be the main cause of the increased mortality rate from the latter disease in certain dusty occupations.

This triad—exposure to dust, fibrosis of the lungs, and high mortality rate from pulmonary tuberculosis—was found to be common to a number of large and important industries, and in all of them the dust incriminated was free crystalline silica (SiO_2).

These features were not observed, however, in other industries in which, while there was exposure to siliceous dust, the silica was found to exist in the combined form as a silicate and not in the free condition.

Thus, shortly, free silica came to be regarded as the pre-eminent cause of industrial fibrosis of the lungs and as a notable factor in the production of the excess mortality rate from pulmonary tuberculosis in certain industries.

Whilst the pulmonary fibrosis produced by free silica (Silicosis) has been, and is being, minutely investigated, the potentialities, as fibrosis producers, of dust other than free silica have not been fully explored, although it appears certain that some other inorganic dusts can, and some cannot, produce fibrosis under the conditions met with in industry.

That a serious, even fatal, degree of fibrosis can be produced by some of these other dusts has not been generally appreciated, although Badham in a thoughtful paper* has drawn attention to this point, in reporting a fatal case of pulmonary fibrosis caused by dust of an orthoclase basalt containing no free silica.

The Nature of Asbestos.—The fibrous minerals commercially known as asbestos fall into the latter group, the silica being combined with metallic bases, mainly magnesium or iron and, to a less extent calcium, sodium or aluminium. The term is a collective name applied to a variety of silicate minerals which differ from each other in chemical composition and physical properties but resemble one another in their finely fibrous nature and flexibility. Their value depends on the facility with which they can be split up into long and flexible fibres for spinning and weaving, on their resistance to heat and acids, and on their insulating properties with respect to heat and electricity. Varieties of asbestos possess these characteristics in differing degree.

Practically speaking, all that goes under the name asbestos in commerce is either fibrous serpentine, or a fibrous mineral of the hornblende group, of which the most important are crocidolite, amosite and tremolite. Serpentine asbestos or chrysotile is essentially a hydrated silicate of magnesium, containing little iron and practically no calcium. The hornblende varieties contain less magnesium and usually more calcium, aluminium and iron—crocidolite and amosite being mainly silicates of iron.

3.—Scope of the Investigation.

Asbestos is very largely used in industry, being an important constituent of many different products. The diversity of industries concerned made it essential that some restriction of the field of investigation should be decided upon.

The manufacturing processes affected fall more or less sharply into two groups (1) those in which there is exposure to pure asbestos or asbestos mixed with a very small percentage of cotton or other vegetable fibre, and (2) those in which there is exposure to a mixture of dusts, of which asbestos is but one.

The former group comprises, in the main, the textile branch of the industry, a branch manufacturing insulating materials from practically pure asbestos, and some preliminary processes in other branches.

The latter group includes a number of processes in which the proportion of asbestos in the dust evolved ranges from a negligible quantity upwards. Since it is impossible to evaluate the effect on the lungs of mixed dusts, of which asbestos dust is only one component, until the action of asbestos dust itself was determined, the examination of workers for the purpose of this enquiry was restricted to workers employed in processes included in group (1), in other words, to workers as nearly as possible exposed to the influence of pure asbestos dust. Furthermore, the effects of previous exposure to other irritant dusts, such as that of free silica, had to be excluded.

The Population at Risk.—The gross number of workers who may be exposed to the inhalation of asbestos dust to any extent is unknown, and, owing to the great variety of processes concerned, there are insuperable difficulties in ascertaining this figure. Nor, in fact, would enlightenment on this point be of any particular value.

It is otherwise, however, with respect to the figure representing the number constantly exposed in the course of their daily work to the influence of pure or almost pure asbestos dust. Some information on this point is very desirable to check the adequacy of the sample of workers examined, and to envisage the problem confronting the industry.

While only a rough approximation is possible, it is believed that about 2,200 is the present number of persons in this country exposed in their daily work to the inhalation of asbestos dust, either pure or admixed with a small proportion of cotton. It should not be overlooked that this figure does not include the considerable number of workers exposed to the influence of mixed dusts of which asbestos is but one, and commonly not more than 20 per cent. of the mixture.

Of these 2,200, the sample examined numbered 363 (excluding 11 for reasons referred to later) or 16.5 per cent.

Selection of Workers for Examination.—The selection of workers for examination was not left entirely to chance, since it was early evident that the proportion of those employed 10 years and upwards in the industry was very small; therefore, in each factory those longest employed were preferred, since the importance of including a sufficient sample of this group is evident. Regard was also paid to the other end of the scale so as to obtain information as to the length of exposure to dust necessary before effects are manifested, and also to the particular process on which the worker was engaged.

By balancing the component groups of the sample in this way as the enquiry proceeded, it was felt that the maximum information would be obtained in the shortest time.

It follows, therefore, that in respect of length of exposure to asbestos dust, the component groups of the sample do not bear the same relationship to each other as the corresponding groups of the industry under review. The subjoined Tables will make this clear. Table 1 shows the distribution according to length of employment (not necessarily in one factory) of 775 workers, the total number engaged on those processes in several factories. Table 2 shows the sample of 363 workers distributed in the same way.

TABLE 1.

Years employed.	Number.	Percentage of Total.
0–4	483	62·3
5–9	200	25·8
10–14	51	6·6
15–19	24	3·1
20 and over ...	17	2·2
Totals ...	775	100

TABLE 2.

Years employed.	Number.	Percentage of Total.
0–4	89	24·5
5–9	141	38·8
10–14	84	23·2
15–19	28	7·7
20 and over ...	21	5·8
Totals	363	100

The enormous preponderance numerically of workers employed under five years is striking, as also is the very low percentage of workers employed 10 years or longer.

Comparison of the two tables shows that the effect of the method of selection of workers for examination is that the number examined in each successive five years employment group is a progressively greater proportion of the total number which could have been examined in each particular group.

With a solitary exception all those examined were at work on the day of examination.

The Clinical Examination and Standards adopted.—The nature and purpose of the inquiry were explained to each worker whom it was proposed to examine, individually, and his or her co-operation obtained. Each individual's previous industrial history, subsequent to leaving school, was noted in detail. This was essential in order to exclude, especially, the effect of previous work in any of the numerous processes involving exposure to free silica dust, and, to a less extent, the effect of other dusts. Similarly, the individual's medical history was scrutinised from childhood onwards, to determine the physical level on entry into the industry and any subsequent changes. Particular attention was paid to accounts of pulmonary ailments, some of which, like asthma and bronchitis, are common enough amongst the general population, yet are also non-specific signs of irritation caused by the inhalation of dust, whilst others, like influenza and pneumonia, are occasionally followed by a degree of pulmonary fibrosis. War service, if any, was gone into, especially as to whether there was any history of the worker having been a gas casualty at any time. The family and personal history in respect of pulmonary tuberculosis was enquired into, and also as to any close association with known cases of this disease in friends or relatives. In approaching the pertinent subject of symptoms, great care was taken to avoid leading questions, especially in eliciting information as to the existence of any undue shortness of breath.

The actual details of the physical examination do not call for comment, inasmuch as they followed the usual lines of a detailed examination of the chest, with observations of the general health and of the condition of the upper air passages.

Reference must be made, however, to the standard of normality adopted in assessing the state of the lungs. The appraisement of any departure from the normal necessarily pre-supposes the existence of such a standard. Every clinician has attained, as the result of experience, his own clear conception of the normal chest, but it is not often that he finds it necessary to define this state in so many words, in fact it seems scarcely possible to do so, and this for several reasons; the heart and lungs function efficiently within wide limits of applied strain, and, although vestiges of past disease may be present and apparent on examination, they will be unimportant if they will never tax the organism beyond these limits, are non-progressive and do not predispose to other disease. Age itself has recognisable effects, but for this reason alone, the chest cannot be considered abnormal.

There is obvious disparity between the standard of physical fitness required for an air pilot and that required for life insurance at ordinary rates; individuals reaching either standard can be classed as "normal," yet many attaining the latter standard have never approached the former.

Thus, within limits, various gradations of normality may be distinguished, and correspondng standards constituted without inaccuracy, the precise status of any standard being determined by the purpose for which it is established. For the purpose of this enquiry the standard adopted has been that evinced in any large group of persons living under similar environmental conditions, apart from work in dusty occupations, as those of the group being considered. This is neither a high standard nor a very low standard, but the average standard of normality displayed amongst the industrial population of this country.

Radiographic Examination of the Lungs.—In addition a careful radiographic examination of the chest was made in many (133) cases, the necessity for which in investigations into the effects of dust upon the lungs has been emphasised repeatedly by various authorities. It was not, of course, feasible to obtain technically sufficient radiograms of all the workers examined, derived as they were from factories scattered over the country, some in districts remote from a radiological centre. The mode of selection was dictated by the needs of the situation, with the object of elucidating material points germane to the investigation, e.g., the elucidation of complicating affections, in measuring the extent and progress of the lesions and locating the point at which the earliest radiographic signs appear, and finally as a check upon the human factor presented by the examiner himself.

4.—Results of the Inquiry.

To anticipate, examination of the data collected in this investigation leads to the conclusion that the inhalation of asbestos dust over a period of years results in the development of a serious type of fibrosis of the lungs.

Asbestosis—the Pulmonary Fibrosis of Asbestos Workers.—It is helpful to visualise fibrosis of the lungs as it occurs in asbestos workers as the slow growth of fibrous tissue (scar tissue) between the air cells of the lung wherever the inhaled dust comes to rest. While new fibrous tissue is being laid down like a spider's web, that deposited earlier gradually contracts. This fibrous tissue is not only useless as a substitute for the air cells, but with continued inhalation of the causative dust, by its invasion of new territory and consolidation of that already occupied, it gradually, and literally, strangles the essential tissues of the lungs.

In common with other essential organs of the body the lungs have a large reserve of tissue for use in emergencies and to permit of a diminution of functional capacity due to advancing age or disease. For this reason, and because fibrosis of the lungs is essentially a local disease, it is only when the fibrosis progresses to the extent of obliterating this reserve, that undue shortness of breath on any extra effort draws the worker's attention to the fact that his health is not what it should be. The other symptoms of the disease such as cough are equally unassuming, and are readily ascribed to some common and trivial cause.

From this point the progress of the disease is more rapid, since it is now encroaching on the remaining sound tissue of the lungs, already only just sufficient to maintain him in his ordinary daily activities. Ultimately, if no acute respiratory infection has precipitated a fatal termination, a stage is reached when the lungs can do little more than maintain life, and the shortness of breath becomes extreme.

In its main clinical features, therefore, the disease resembles silicosis, as might be expected. It differs from silicosis, however, in the mode of distribution of the fibrous tissue in the lungs, in its more rapid development, in its radiological features, and, there is some reason for believing, in a lessened susceptibility to the supervention of pulmonary tuberculosis, the liability to which disease is so definitely an added hazard in silicosis.

The Asbestos Bodies.—In the lungs of those exposed to asbestos dust, angular particles derived from asbestos,[7] and spicules of asbestos[11] are found on microscopical examination, and also numbers of peculiar bodies described by Cooke and Hill[7] and Stuart McDonald[8]. They are yellowish brown in colour, of elongated, bead-like form, often with bulbous ends. Cooke[9] and Roodhouse Gloyne[9] independently demonstrated a mineral core in these bodies, evidently derived from the asbestos fibre. Stewart and Haddow[10] have also demonstrated their presence in the sputum of asbestos workers. These bodies have not been found to occur in any other human affection. They have been found in the sputum within a comparatively short time after exposure to asbestos dust, and in the absence of clinical or radiological evidence of pulmonary fibrosis, their presence cannot be taken at present as indicating anything more than previous inhalation of asbestos dust.

The Incidence of Pulmonary Fibrosis in Asbestos Workers.—The extent of the risk to health associated with exposure to asbestos dust under present industrial conditions may now be considered in detail.

Of the 374 workers of both sexes examined, 105 were found to have a diffuse fibrosis of the lungs attributable to the inhalation of dust. Ten of these, and one other in which there were earlier signs of the same condition, have been excluded from further consideration, inasmuch that it was felt that previous work in other dusty occupations, such as quarrying, and coal mining, may have been the prime or a contributory factor in the development of the pulmonary lesions found.

Thus, 95 of 303 workers, or 26.2 per cent. showed a definite fibrosis due to asbestos dust. An additional 21 were found with precursive signs of this disease, but these are given no weight in the general conclusions, which are derived solely from examination of the 95 cases of definite fibrosis.

Of the 133 radiographed, 62 presented radiographical signs of a diffuse fibrosis, and in a further 25 there were suggestive radiological changes not definitely diffuse fibrosis. In 10 of the former group and 3 of the latter the changes were possibly referable to prior work in other dusty occupations or to other cause, and they are therefore excluded, leaving 52 cases of fibrosis and 22 with signs suggestive of early changes in the lungs due to asbestos,—sufficient radiological confirmation.

What inferences should be drawn from these figures?—Certainly not that 26.2 per cent. or roughly 1 in 4 of those at present exposed to asbestos dust in their daily work have fibrosis of the lungs. As mentioned previously the sample examined is loaded with a greater proportion of workers employed 5 years and over than obtains in these sections of the industry at the present time (Tables 1 and 2 above), and as shown in Table 3 below the incidence of fibrosis increases with the length of employment. Therefore in order to obtain an approximation of the general incidence rate of fibrosis in these sections of the industry a correction must be applied on this account. Applying the rates shown in Table 3 to the figures in Table 1, it appears that the general incidence rate of fibrosis of the lungs amongst those employed in these sections of the industry is rather less than 1 in 8, or, excluding those employed under 5 years, rather less than 1 in 3.

Further corrections would have been necessary if the sample had included an undue proportion of workers from the more dusty processes, but this was found not to be the case. Also no correction is required on account of differing age distribution since, as will be seen later, the incidence of fibrosis is unaffected thereby. Sex has no effect.

These general incidence rates are convenient merely as affording a rough indication of the inherent risk associated with exposure to asbestos dust at the present time. They have no permanent value either as an index of the general risk of fibrosis in the industry from year to year, or as a measure of the risk in any particular factory or group of employees. This must be so since not only will the distribution of workers in the industry according to process and length of employment vary from year to year in accordance with trade developments, but the increasing application of methods for the suppression of dust will have a cumulative effect in reducing the fibrosis incidence rate in future years.

Effects of Age and Length of Employment.—Table 3 shows the distribution of the workers examined according to length of employment, and Table 4 their distribution according to age, together with the incidence rates of fibrosis in each case.

TABLE 3.—*Incidence of Fibrosis relative to Length of Employment.*

Years Employed.	Number Examined.	Cases of Fibrosis.		Average age in years.	
		Number.	Group Incidence per cent.	Of Group less cases of Fibrosis.	Of cases of Fibrosis.
0–4 ...	89	0	—	24·2	—
5–9 ...	141	36	25·5	30·3	36·0
10–14 ...	84	27	32·1	34·4	40·4
15–19 ...	28	15	53·6	41·9	43·3
20 and over ...	21	17	80·9	54·4	52·7
Totals ...	303	95	26·2	30·1	41·4

TABLE 4.—*Incidence of Fibrosis relative to Age.*

Age Group	Number Examined.	Cases of Fibrosis.		Average length of employment in years.	
		Number.	Group Incidence per cent.	Of Group less cases of Fibrosis.	Of cases of Fibrosis.
Up to 19 ...	23	0	—	3·2	—
20–29 ..	150	14	9·3	6·2	8·7
30–39	100	30	30·0	9·1	12·2
40–49 ..	47	31	65·9	11·3	14·2
50–59 ...	29	11	37·9	9·7	16·9
60 and over	14	9	64·3	16·0	19·0
Totals ..	363	95	26·2	7·5	13·5

These tables indicate the outstanding importance of length of employment (and hence length of exposure to dust), and the negligible effects of age, on the production of fibrosis.

Thus age groups 30/39 and 50/59 (Table 4) have incidence rates of 30 per cent. and 37.9 per cent. respectively, not a wide difference, since the groups include workers in various processes exposed to different concentrations of dust. Moreover, the average length of employment in these two groups, excluding the cases of fibrosis, is almost identical, but considerably less than the average length for all the cases of fibrosis (13.5 years).

It appears also from the same Table that no special susceptibility to the development of fibrosis is shown by young persons, unless it is considered that the figure of 8.7 years, the average length of employment of the cases of fibrosis in age group 20/29, has been shortened by increased susceptibility of ages under 20. As, however, the average age of this group at cases of fibrosis is 26.7 years, and also because the establishment of fibrosis does not necessitate immediate retirement from work, this is largely discounted.

Column 4 of Table 4 also shows a general irregularity which, in itself, points strongly to the negligible effects of age in the production of fibrosis.

Turning to the effects of length of employment a very different picture is seen. Table 3 shows that after 5 years' exposure, the incidence rate mounts rapidly, and after 10 years increases almost in geometrical progression.

Effect of Work in different Processes.—There are insuperable difficulties in ascertaining trustworthy figures of the precise incidence of fibrosis amongst workers in particular asbestos processes. This is the result of the common practices in the industry of housing many processes in one room, and of workers transferring from one process to another. These two factors, the influence of dust from neighbouring processes, and prior work in other asbestos processes, operate to obscure the effects due to work in any one process.

By distributing the workers, however, according to the process in which each has been longest employed and grouping similar processes together, it is possible to draw certain broad conclusions as to the relative effect of work in different processes. In this way groups were obtained as follows:—

(1) Crushing, opening, disintegrating and mixing.
(2) Carding.
(3) Spinning, twisting, doubling, plaiting, etc.
(4) Insulating mattress making.
(5) Weaving and associated processes.
(6) Miscellaneous processes and remaining unclassified workers.

The outstanding point brought out in this way is the relatively very low incidence rate of fibrosis in group 3 (termed "spinners" for convenience) as compared with each of the other groups. There is some indication also that amongst "spinners" the disease takes longer to develop. Study of the radiograms, also, reveals further indications confirmatory of this. Moreover, estimations of the dust content of the air in the neighbourhood of these processes and in that of others in the various groups show that the evolution of dust in group 3 is also relatively low (Table 5).

In fact, the history, and the medical and radiological features of the cases of fibrosis, together with the results of comparison of the dust counts, all contribute in some degree to the view that with comparatively low concentration of dust in the neighbourhood of a process, the resulting cases of fibrosis amongst the workers in that process are longer in developing and remain longer in a milder stage. It follows, therefore, that in such cases the rate of accumulation of dust in the lung has not greatly exceeded the rate of elimination, and a further point of great practical importance emerges, namely, that in order to prevent the full development of the disease amongst asbestos workers within the space of an average working lifetime, it is necessary to reduce the concentration of dust in the air of the workrooms to a figure below that pertaining to spinning at the time over which these cases were exposed.

Not only does group 3 show the lowest incidence of fibrosis, but it forms the largest individual group in these sections of the industry—about one third

Relative Dustiness of Various Asbestos Processes.—While some reference here to the varying amount of dust evolved by the different processes is necessary, the causation of these differences and methods of suppression of dust are discussed in Part II of this Report.

Different asbestos processes do cause the evolution of different amounts of dust into the air of the workrooms, and, under present conditions, the difference between the least dusty and the most dusty processes is very pronounced.

In some processes the production of asbestos dust is insignificant; in a second group dust is continuously evolved but in relatively low concentration, as in spinning; in a third group the evolution of dust is continuous and in high concentration, as in dry cloth weaving; and in a fourth group much dust is dissipated in bursts of short duration, as in emptying the fibre from settling chambers by hand into bags.

Some additional data were obtained by means of a limited number of determinations of the dust content of the air at the breathing level of operatives engaged in various processes, with the aid of the Owens' Jet Apparatus. The figures in Table 5 which were calculated from some 50 determinations, give a rough idea of the general dustiness of the processes concerned, and also of the effect of localised exhaust ventilation and damping in reducing the concentration of dust in some of them. The counts in other processes are expressed proportionately to the spinning, plaiting and braiding group, taken as unity.

It will be seen from this Table that the dustiest processes are opening (with old fashioned teasers), sieving (with no local exhaust ventilation), and shovelling or otherwise handling asbestos fibre, with a comparative figure of 2.34. The heaviest counts of all were found in this group, in sack filling by hand in a settling chamber. The comparative figure here was 6.84, but the record was dense, with much clumping together of the dust particles, with the result that the total dust count arrived at was undoubtedly too low.

Next in order is dry cloth weaving without the application of localised exhaust ventilation, with a figure of 1.95. This is undoubtedly a dusty process, and although local exhaust ventilation reduces the count at the breathing level of the weaver, much dust still escapes into the workroom. Weaving cloth wet, not merely damp, reduces the dust count to a remarkable degree. Column

TABLE 5.—*Relative Dustiness of various Processes and Effects of Localised Exhaust Ventilation and Damp Methods in suppressing Dust.*

Spinning, Braiding, Plaiting, without local exhaust ventilation.	Carding, with local exhaust ventilation.	Weaving. Cloth. Dry. Without local exhaust ventilation.	Weaving. Cloth. Dry. With local exhaust ventilation.	Weaving. Cloth. Wet.	Weaving. Band. Dry, with local exhaust ventilation.	Weaving. Band. Wet.	Mattress Making. Dry, without local exhaust ventilation.	Mattress Making. Dry,* with exhaust ventilation.	Mattress Making. Damp,* with exhaust ventilation.	Opening and handling fibre, without local exhaust ventilation.
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	1·17	1·95	1·05	·95	·81	·91	1·93	·69	·55	2·34

* Note that here the exhaust ventilation means special general ventilation of the mattress making workrooms, not localised at the work benches.

7 for band (i.e., narrow) weaving, wet, is not accurate since the figure has been raised by dust from a neighbouring dry cloth loom.

Mattress making without any precautions, such as exhaust ventilation, or damping floors, tables and cloth, follows next with a figure of 1.53 (See footnote Table 5). Application of exhaust ventilation, and damping reduces the figure considerably, but it may be that the figures in columns 9 and 10 are too low, since counts for some subsidiary processes, such as buttoning, sewing and cutting out, are not available.

It will be observed that carding, although essentially a very dusty process, produced a comparative figure of only 1.17. This is due in part to partial enclosure of the working parts of the carding machine, but is mostly the result of the application of local exhaust ventilation. Moreover, the figure does not take into account the extremely dusty operation of stripping.

Relative to the comparative numbers for the other different processes, the figure of 1 for spinning, plaiting and braiding is probably rather too high, owing to contamination by dust from neighbouring and more dusty processes.

Samples of asbestos vary much in chemical constitution and physical properties, and of the three main varieties, chrysotile, crocidolite, and amosite, the latter two, in the opinion of experienced workers, usually give rise to more dust than chrysotile in the textile manufacturing processes. No evidence was found to indicate that any one of the three varieties is more, or less, potent than the others in producing fibrosis, other factors, such as concentration of dust, being equal. A peculiarity of the asbestos fibre is that it first fragments longitudinally, and apparently this process can go on indefinitely, since there is no ultimate fibre comparable to a vegetable fibre such as cotton.

Concentration of Dust and Length of Exposure Necessary to Produce Fibrosis.—From the data so far examined it seems clear that fibrosis of the lungs is a definite occupational risk amongst asbestos workers as a class. Furthermore, it appears that the risk falls most heavily on those longest employed and on those engaged in the more dusty processes.

Some further consideration of these two important factors, length of employment and concentration of dust, is desirable. Obviously, to some extent, they are interdependent, since, assuming that a specific quantity of asbestos dust must be inhaled to produce a generalised fibrosis, the fibrosis will result from exposure for a period of time varying with the concentration of dust in the air breathed.

Simson[11] reports the case of an asbestos mill worker in South Africa, exposed for 12 months to a very dusty atmosphere, who died from a rapid tuberculosis; sections of the lungs showed, apart from the changes due to tuberculosis, a moderately marked fibrosis. Burton Wood and Page[12] report the case of an asbestos spinner, employed 15 months, who died from a generalised tuberculosis, 8 months after ceasing work. In this case a little fibrous tissue was generally to be seen surrounding the asbestos fibres found in the lung tissue, but there was no gross fibrosis. It seems probable, therefore, although further research is very necessary, that not only is a certain minimal quantity of the dust required for the production of a generalised fibrosis, but that inhalation of the dust in high concentration results in the production of a more marked degree of fibrosis in a shorter time, than when the concentration is low.

Investigation of this important matter—concentration of dust and length of exposure necessary to produce fibrosis—from the clinical side is beset with difficulties, one of the most confusing being that the existence of a clinically recognisable diffuse fibrosis is quite compatible with continued work in the industry, and, therefore, the cases of fibrosis discovered in such an investigation as this are in various stages of the disease, with the result that the point at which they first became recognisable clinically cannot be ascertained.

Despite this, some confirmation of the hypothesis that the length of exposure to asbestos dust necessary to produce fibrosis varies inversely with the concentration of the dust in the air, within certain low and high limits, may be obtained.

Table 6 shows the average age and length of employment of the cases of fibrosis in the groups of processes previously dealt with (p. 11).

TABLE 6.

Process.	Cases of Fibrosis.	
	Average Age.	Average Length of Employment
1. Crushing, opening, disintegrating, mixing ...	43·1	10·9
2. Carding	39·0	13·2
3. Spinning, twisting, doubling, plaiting, &c. ...	37·0	18·7
4. Mattress making	38·1	13·0
5. Weaving and associated processes	43·5	12·7
6. Miscellaneous processes and remaining unclassified workers.	42·1	13·8
Totals		13·5

The much longer average period of employment of the cases of fibrosis in group 3 as compared with the other groups will be noted. There is also least exposure to dust in group 3. It seems, therefore, that in this group a longer period elapsed before the fibrosis developed, or that it progressed less rapidly.

This is the more apparent if the incidence rates of fibrosis amongst workers employed in the processes in group 3 are compared with the corresponding rates for workers employed in the more dusty processes comprised in groups 1, 2, 4, 5, taken together. These rates are set out in Table 7.

TABLE 7.—*Comparison between the Incidence Rates of Fibrosis amongst Workers employed in Group 3 (less dusty processes) and the Incidence Rates amongst Workers employed in Groups 1, 2, 4, 5, taken together (more dusty processes).*

—	Years Employed.														
	0–4.			5–9.			10–14.			15–19.			20 and over.		
	No. Examined.	Cases of Fibrosis.	Incidence Rate.	No. Examined.	Cases of Fibrosis.	Incidence Rate.	No. Examined.	Cases of Fibrosis.	Incidence Rate.	No. Examined.	Cases of Fibrosis.	Incidence Rate.	No. Examined.	Cases of Fibrosis.	Incidence Rate.
			Per cent.			Per cent.			Per cent.			Per cent.			Per cent.
Group 3	30	0	—	40	2	5·0	30	2	6·7	11	4	36·4	6	4	66·7
Groups 1, 2, 4, 5 (taken together).	47	0	—	92	31	33·7	45	22	48·9	14	8	57·1	13	11	84·6

Group 3 = Spinning, twisting, doubling, plaiting, etc.
Groups 1, 2, 4, 5 = Crushing, etc., carding, mattress making and weaving and associated processes.

It will be seen that, after 5 years' employment, the rates are consistently much higher amongst those employed in the more dusty processes, and, whereas the rate is high from about 5 years onwards in the more dusty processes, it is not until about the 15th year of employment is reached in the less dusty processes that the rate for the latter becomes high, and approximates to that reached after about 5 years' employment in the more dusty processes.

Exposure to different concentrations of dust, together with the effect of the recognition of the cases of fibrosis in different stages of the disease, also afford an explanation of the widely differing lengths of employment of individual cases of fibrosis, which ranged from 5 years to over 30. While no definite case of fibrosis clearly due to asbestos dust was found amongst workers with less than 5 years exposure, the possibility of such cases occurring with exposure to high concentrations of dust cannot be ruled out. Three cases were found with 3, 3½ and 4½ years work in asbestos, respectively, but in each there was previous exposure to other dusts (see p. 10).

Support for this view is provided by (1) Professor Beattie's experiments previously mentioned, which demonstrated that the lungs of guinea-pigs exposed for 43 and 67 hours to asbestos dust showed "definite cellular proliferation, though not very extensive, and this is certainly a preliminary stage in the production of fibrosis"; (2) Simson's case mentioned above, and his report in the same paper on the lungs of a guinea-pig exposed by Mavrogordato to asbestos dust for 100 hours during a period of 56 days. On the death of the animal (from causes other than asbestosis) some 32 months later, sections of the lungs showed a slight generalised fibrosis. In commenting on the amount of fibrosis found, he states that "a comparison between the human cases and the experimental animal showed that the fibrosis was more rapid and extensive in the human cases than in the experimental animal," and again "the amount of fibrosis in two of the human cases was quite rapid, and if due to the presence of asbestos dust, the initial rate of production was rapid when compared with present day non-infective silicosis on the Rand"; (3) data from this investigation, in which 21 of the 363 workers showed signs suggestive of commencing fibrosis (p. 10). Of these 12 had been employed for less than 7 years, and 6, for between 4 and 5 years.

To sum up, therefore, it appears probable that concentration of dust and length of exposure as factors in the production of fibrosis are interdependent within certain limits. While it seems necessary for the production of generalised fibrosis of the lungs that a definite minimal quantity of dust must be inhaled. the lower the concentration of dust in the air breathed, the longer the lapse of time before the fibrosis is fully developed, and within a certain limit, the higher the concentration of dust, the sooner the fibrosis becomes fully developed and the more intense the involvement of the lung tissue.

If this hypothesis is correct, and the evidence points to it, the practical inferences are of very great importance, since it follows that the application of measures resulting in the reduction of the concentration of dust in the air in the neighbourhood of dusty asbestos processes will cause, firstly a great increase in the length of time before workers develop a disabling fibrosis, and secondly, the almost total disappearance of the disease, as the measures for the suppression of dust are perfected.

Disablement produced by the Asbestos Fibrosis.—Regarding the amount of disablement produced by the development of pulmonary fibrosis in asbestos workers,—for a number of years this is surprisingly slight, even more so than is generally the case in silicosis. This is partly due to the character of the disease, and partly to the nature of the work, which in the majority of these processes does not involve much physical exertion. The affected person may, and often does, continue at work with occasional intermissions, latterly, due to exacerbations of bronchitis, until the condition is advanced, although he suffers increasing inconveniences from shortness of breath, on exertion. Sometimes a terminal broncho-pneumonia, or other acute infection, commences while still at work, and there is no long period of invalidism.

There is no doubt but that fibrosis of the type produced by asbestos can of itself lead to complete disablement and to a fatal termination, and this in the absence of a superadded tuberculous infection.

Particulars have been collected up to the end of 1929 of 10 cases in which an advanced degree of the asbestos fibrosis without tuberculosis was the primary cause of death. In 9, the cause of death was verified by post mortem examination and in the 10th, repeated clinical, radiological and sputum examinations confirmed the diagnosis. In an 11th case, post mortem examination showed that a lobar pneumonia had supervened upon lungs already the seat of a moderate degree of the asbestos fibrosis. With one exception, all these deaths occurred in the years 1927-29.

The length of exposure to asbestos dust in these cases varied between 9 and 24 years.

It is not suggested that these few fatalities, in which the cause of death has been verified by strict enquiry, are any criterion of the true effect of the disease on the mortality rates of asbestos workers. Others are known to have occurred in which the existence of the asbestos fibrosis has been determined in life, but no post mortem examination has been possible.

Progress and Duration of the Disease.—The rate of progress and duration of the disease varies within wide limits. With continued exposure to high concentrations of dust, the fibrosis may be fully developed in from 7 to 9 years, and may cause death after about 13 years exposure, exceptionally in a shorter period. On the other hand, with exposure to less concentrations of dust, the period of maturation of the fibrosis may be extended to 15, 20 or 25 years. There are definite indications, derived from the industrial histories and examination of workers, that a diminution in the concentration of dust in the air breathed, either by change of employment from a highly dusty process to one less dusty, or the effect of methods taken for the suppression of dust, results in a prolongation of this period of maturation of the fibrosis, except in the late stages of the disease. While this is so, the existence of a clinically recognisable degree of the asbestos fibrosis in any individual is an additional adverse factor in the prospects of recovery from any acute infection of the lungs, such as pneumonia or broncho-pneumonia.

Association of the Asbestos Fibrosis with Pulmonary Tuberculosis.—As previously mentioned (p. 6), silicosis, the fibrosis of the lungs due to the inhalation of free silica dust, has an unhappy association with pulmonary tuberculosis, in that there is a much increased liability to the supervention of the latter disease amongst silicotics. It is of importance, therefore, both from the point of view of the individual worker, and in its bearing upon the scope of the preventive measure required, to enquire whether there is a similar liability attached to the asbestos fibrosis.

It will be remembered that in this investigation the examination of workers was restricted to those at work at the time of the examination, and, therefore, a number of advanced cases of fibrosis, and a number of cases of pulmonary tuberculosis—with or without an asbestos fibrosis in addition—who had either given up work or who were off work temporarily, will have been missed. Moreover, the supervention of a tuberculous infection on a lung already the subject of fibrosis produces an increase in symptoms, previously unnoticed or disregarded, and induces the worker to seek medical advice. He is then appropriately advised to give up his dusty employment, migrates from the industry, and may or may not accept sanatorium treatment.

Thus there tends to be a drift of such cases from the fibrosis producing industry. In fact, during the course of the investigation, information was obtained of a number of persons, previously employed in asbestos, who were either at home or in sanatoria, suffering from chest complaints.

Precise information as to the incidence of pulmonary tuberculosis amongst asbestos workers cannot be obtained therefore, in the absence of periodical medical examinations in the industry, without prolonged enquiry involving the search of the records of local sanatoria, tracing workers known to have ceased work in asbestos, and examination of death certificates, and of the sickness records of firms, where these are kept.

Nevertheless, with these reservations, the data obtained in this investigation did not disclose any outstanding susceptibility to pulmonary tuberculosis, either amongst asbestos workers as a class, or amongst the cases of fibrosis.

Summary.—The outcome of this investigation is to establish the existence of a definite occupational risk in the asbestos industry. This takes the form of a distinct type of fibrosis of the lungs, resembling silicosis in its main clinical aspects, but differing from that disease in the mode of distribution of the fibrous tissue in the lungs, in its radiological features, in the enhanced rate of development under average conditions in this country, and as far as the evidence goes, in a lower susceptibility to the supervention of pulmonary tuberculosis.*

The asbestos fibrosis results from the inhalation of asbestos dust, the proximate causes being concentration of dust in the air breathed and length

* The medical and radiological data obtained in this investigation will be published elsewhere.

of exposure to it. Thus the incidence rate is highest in the most dusty processes and amongst those longest employed. Age and sex have no apparent influence on the production of the disease.

5.—Factors Determining the Present Recognition of the Asbestos Fibrosis.

It is of interest to consider why it is that this disease has only recently attracted notice and become a problem in the industry, although asbestos was known to, and worked by the ancients.

Many factors contribute to this position, some dependent on the nature of the disease, some on the phenomenal expansion of the industry, others on the advance of medical science.

While asbestos has been known and spasmodically worked for hundreds of years, it is only in the past 40 years or so that it has been commercially exploited to any extent. Not only that, but it is less than 30 years since the great expansion of the industry commenced. Even after a number of years of steady expansion, the industry is still comparatively small, and the workers employed in the essentially dusty processes relatively few.

The insidious onset and unobtrusive signs and symptoms of the disease in its earlier course, its covert advance by imperceptible stages, its points of resemblance latterly to fibroid tuberculosis, with which infection it is sometimes associated, and the migration of those affected from the industry, have all combined to delay its recognition as an entity, and to obscure the causal agent.

Knowledge of the effects of specific dusts upon the lungs has been greatly extended in the past 20 years, but research has been mainly concerned with the more important and widespread risk associated with the dusts containing free silica, and enquiry into the effects of other dusts had to wait upon those investigations.

6.—Preventive Measures.

The necessary preventive measures include, first, those directed specifically towards the suppression and control of the dust evolved in manufacturing processes, which are examined in Part II of this Report, and secondly, measures directed towards those employed in the industry.

These latter include the control of the disease by periodical medical examination of the workers, by which those unfitted by health reasons are prevented from entering the industry, and cases of fibrosis and pulmonary tuberculosis are detected at the earliest possible moment. The ultimate and only reliable test of the effectiveness of the preventive measures adopted in the industry will be found in the statistics derived from the records of periodical medical examination of the workers.

They also include the education of the individual, as in other dangerous trades, to a sane appreciation of the risk, and to his personal responsibility in the prevention and suppression of dust.

The protection afforded by respirators is only partial, and there is a real danger that the use of them may give a sense of false security. Asbestos dust floating in the air contains a majority of particles of the order 2μ, and under, many being only 0.5μ ($\frac{1}{50,000}$ inch) in size. In practice, the discomfort of constant wear, and difficulty in speech, etc., render workers very unwilling to use this form of protection for any length of time. Since, however, a high class respirator will trap a proportion of the large particles which can enter the lung, they cannot be said to be valueless, but can only be recommended as a second line of defence, and not in substitution for other preventive measures specifically directed to the control of dust as near as possible to its point of origin. Under very exceptional circumstances there may be scope for the use of the efficient type of breathing apparatus, comprising a mask or helmet with a long tube, enabling the wearer to breathe pure air from a distance.

7.—The Outlook.

From consideration of the nature of the processes in the asbestos industry and other relevant matters, it is felt that the outlook for preventive measures is good. That is to say that in the space of a decade, or thereabouts, the effect of energetic application of preventive measures should be apparent in a great reduction in the incidence of fibrosis.

An immediate temporary rise in the incidence rate is probable, due to the accumulated damage, partly a legacy of the war years, but with the passing of the peak, a steady fall should ensue.

Much generous assistance has been received from many sources during the course of this investigation; these are gratefully acknowledged elsewhere. Special thanks are due, however, to Dr. E. W. Twining of Manchester and Dr. N. Tattersall of Leeds for their indispensable expert assistance in the elucidation of the radiological features, to Dr. W. E. Cooke, Professor M. J. Stewart, and Dr. Roodhouse Gloyne, whose researches in the same field are well known, and to Dr. I. M. D. Grieve for information from an unpublished study of a group of asbestos workers.

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PART II.

Processes Givin- Rise to Dust and Methods for its Suppression.

1.—Introduction.

The asbestos industry has developed greatly in recent years and continues to expand rapidly, mainly because of the demands of the motor, electrical, engineering and building industries, and of the increasing attention now paid to the insulation of steam plant to promote fuel economy.

Asbestos products may, for convenience, be divided into seven main groups :—

Textiles.

(a) Yarn and cloth.

Non-Textiles.

(b) Millboard, paper, asbestos-cement sheets, tiles, and other building materials, sheet material of rubber or bituminous mixtures containing asbestos.

(c) Insulation materials and articles.

(d) Brake and clutch linings.

(e) Packing and jointings.

(f) Asbestos-covered electric conductors—electrodes, cables and wiring, coils for electric machinery.

(g) Miscellaneous, including moulded electrical and other goods, etc

Some factories make both textile and non-textile goods. So-called "fiberized" asbestos, i.e., opened or broken-up material in a fine flock-like condition, is manipulated, unmixed with other materials, in large quantities in the factories included in groups (*a*), (*b*), and (*c*), and to a much smaller extent in some of the other factories and workshops.

(*a*) Asbestos yarn is woven into cloth for insulation mattress coverings, insulating wrappings, filtering material, fire curtains, fire-smothering blankets and fire-resisting clothing. Narrower woven material is produced for belting for conveyors, brake linings and insulating tape. Some asbestos cloth is rubber-proofed for use in the manufacture of steam packings and jointings.

Besides its main use for weaving, asbestos yarn is braided and plaited for use as packing, and also for insulating material. Spools of yarn are supplied to factories in which electric cable or electrodes are made, and polished thread for the completion of incandescent mantles.

(*b*) Asbestos millboard and paper are manufactured from pulp containing short fibre asbestos, by a wet method, like ordinary millboard and paper. Asbestos-cement sheets, tiles, gutters, pipes, etc., for building and similar purposes are made from wet mixtures of Portland cement and short fibre asbestos. A synthetic composition sheet is made from a rubber mixing, for use as jointing. Bituminous mixings containing asbestos are made for switchboard panelling, and other mixings for floorings.

(*c*) Insulation materials include fiberized asbestos; "magnesia," so-called containing about 15 per cent. of fiberized asbestos and 85 per cent. of magnesia, and other finely divided mixtures composed partly of fiberized asbestos, used as insulating cements or plasters; fiberized asbestos stiffened into thick sheets, like mats, for lining bulkheads of ships; shaped sections and slabs, moulded from fiberized asbestos or mixtures containing it, or built up of corrugated asbestos paper so as to enclose air cells; mattresses, made of asbestos cloth and filled with fiberized asbestos, magnesia, or other filling.

(*d*) Brake and clutch linings are chiefly prepared from impregnated and heat-treated asbestos cloth, but also from moulded asbestos material.

(*e*) Plaited and braided asbestos yarn, proofed asbestos cloth and composition sheet are used in making packings and jointings.

(*f*) Electrodes for welding work are plaited with asbestos yarn or covered with a paste containing asbestos. Some electric cable and wiring required to withstand heat are plaited with asbestos yarn; field coils for electric machinery may be wrapped with asbestos tape.

(*g*) Miscellaneous manufactured articles or products, composed wholly or partially of asbestos, include, in addition to moulded electrical and other goods, asbestos putty and powder, rubber hose plaited with asbestos yarn, and many others.

Apart from manufacture, certain work is carried on in premises subject to the Factory and Workshops Acts, as well as in other premises, which involves use or manipulation of asbestos or products containing it. The insulating of boilers, pipes, engines, and parts of ships is the most important. Much of this work is done on board ship by contractors who employ a considerable outdoor staff.

2.—Premises.

The factories and workshops included in (*a*) to (*g*) number at least 160, of which 18 are textile factories. This total is based on lists supplied by the District Inspectors. It does not include the large number of works where there is incidental use of asbestos packing and jointing, asbestos-covered electric cable or other finished goods, required for completing other manufactures.

There is only one works in which the employees concerned with asbestos exceed 500. There are many small premises in which but a few employees, in some cases only one or two, are employed. A small "asbestos" department is found in a number of important factories.

Textile departments are usually well housed in modern buildings. A few of the older textile factories have been improved recently by the addition of modern buildings. In one case a badly housed small concern is in process of removal to newly constructed premises.

The asbestos-cement sheet factories are modern premises of large floor area, lofty and spacious, in the main, single storey buildings. The cable and electrode factories are also modern and generally suitable.

Some small works, more particularly those engaged in making boiler compositions, are unsatisfactory. A few are mere open-sided sheds. Such premises are difficult to keep clean.

Some works are congested with plant and stocks of material. This may result from inadequate accommodation or a temporary falling-off in the demand, but the effect on cleanliness is bad. The dust evolved in manufacturing processes is more difficult to control if the premises are unsuitable, particularly if crowded with plant or material. Cleaning is not easily accomplished and the dust is more concentrated.

Ventilation.—The arrangements provided for ventilating asbestos works vary as in other industries. Dust removal systems, where used, effect a measure of general ventilation. A number of workrooms in textile factories are ventilated by plenum systems, the air supply being warmed in winter. Overhead extracting propeller fans are but little used now and would be unsuitable. In one mattress making room extraction fans connected to large overhead hoods are used. Extraction by downward displacement, the air being drawn through openings in the floor, or near floor level, has not been met with, but has been considered for some weaving rooms. This system, if designed of a capacity sufficient to effect a high standard of general ventilation, would tend to reduce the dust in the general atmosphere at breathing level, and, with other safeguards, be a possible alternative to localised exhaust ventilation. It could not be successful without efficient heating, owing to the rapid change of air entailed.

Separation of Processes.—In many works several processes are carried on in the same room. In the absence of effective means of preventing escape of dust into the air, many workers are subjected to a risk from which they would otherwise be immune, or to a greater risk than that arising from their own work. In a few textile factories crushing and opening plants are placed close to spinning and carding machines. Spinning frames are installed close to looms and wet and dry weaving are carried on close together. In non-textile premises there is more effective separation of dusty work and processes from non-dusty.

3.—Description of Processes and Preventive Measures.

A complete account of manufacturing methods is not attempted. Attention is mainly directed to the dust-producing processes, a description of which, in broad outline, has been deemed necessary to make clear the circumstances under which exposure to dust arises, and the character and object of the remedial measures already in use or here recommended.

Somewhat important changes are on foot which, it is confidently hoped, will greatly reduce exposure to dust in certain hitherto dusty processes. On the other hand, certain developments, e.g., speeding up of textile machinery, and the increased use of asbestos in various industries, may intensify the dust problem, if adequate measures to deal with the dust are not taken.

Textiles.

(a) Yarn and Cloth.

The manufacture of asbestos yarn and cloth proceeds on the whole like that of other textiles, but there are some important differences. Fiberized and other asbestos material is freely handled in various operations, in gathering "waste," and in cleaning. Exposure, in some degree, to asbestos dust, is common throughout all the factories, but steps have been taken, extending over many years, to deal with dust produced at various points, though the necessary degree of efficiency has, generally speaking, not been reached. Exhaust ventilation plants used in the best-equipped asbestos factories for removing dust appear to be as efficient as those used in other textile industries, and to have been applied over a wider field. As regards other safeguards against dust, e.g., substitution of mechanical methods for handwork for feeding the machines in preliminary operations, efficient enclosure of machines, and vacuum methods of cleaning, little development has been made.

Opening.—Asbestos, suitable for yarn, has usually to be crushed, and in all cases "opened" ("fiberized") before it is ready for carding. These preparatory processes are effected by machinery, but entail much handwork. Separating (to remove iron) and grading or sieving follow crushing, but precede opening

Material for yarn is not usually treated in disintegrators, but in most factories these machines are used for fiberizing waste asbestos yarn, etc. Crushing flattens out and breaks up the mineral without damaging the fibres. It is accomplished either in a large edge runner, or in a small pan mill of the mortar mixing type. The material is emptied upon the floor close to the machine, the contents of several sacks sometimes being spread on the floor to obtain a rough " mixing. The crushed material is either taken from the machine by hand, or discharged through a bottom delivery slide, usually filled into sacks or skips and, if necessary, weighed on a portable weighing machine. A few edge runners discharge upon short inclined lattices and the material falls automatically into the sack or skip.

Edge runners give rise to dust of considerable amount where short fibre is crushed; some are enclosed and have exhaust applied. This is always necessary. Pan mills are not enclosed and also give rise to dust, though less in amount.

Handwork, e.g., sack emptying and filling, mixing, shovelling and feeding machine pans or lattice feeds, gives rise to dust, sometimes of considerable amount, and is done without exhaust. Application of exhaust draught would be facilitated if feeding were done from a higher level so that sacks might be emptied under enclosed conditions, i.e. in a sack emptying apparatus. Automatic delivery and reversible bagging lattices eliminate dust produced in hand filling of sacks, but require to be efficiently enclosed with exhaust draught applied.

An open travelling band passing round an electro-magnet is used for separating loose iron, the asbestos being delivered to an elevator. Enclosed apparatus should be adopted.

Enclosed rotary sieves (rotaries) or long oscillating frame sieves are used for roughly grading crushed material. Rotaries should be mechanically fed and the asbestos collected under enclosed conditions (not always done) and exhaust applied to the machine enclosures, otherwise unnecessary dust is created. Some oscillating sieves are very open, the material being allowed to fall on the floor, and being filled into sacks by hand. Very dusty conditions are then inevitable. Efficient enclosure with exhaust draught applied and, to avoid hand filling, automatic delivery and bagging lattices, also enclosed and exhausted, as used in some cases, are generally practicable.

Crighton openers, enclosed centrifugal machines, are used for opening crushed asbestos, preparatory to carding. Careful mixing or blending of crushed material is effected by spreading it evenly in layers on the floor over a considerable area—cotton may be added at this stage if required—and when feeding, taking a vertical cut through the mass. Admixture with a small proportion of cotton may also be achieved by blowing it into the feed opening. The opened material is delivered upon a lattice and collected either in a large container or in sacks, automatic bagging lattices being used in some cases. Mechanical feeding under enclosed conditions, with exhaust draught applied to feeding lattices or other conveyors, should be adopted. Hand feeding gives rise to dust, from sack emptying, shovelling and particularly mixing on the floor. Mixing is a great hindrance to elimination of hand work; it is asserted that poor yarn results if it is not done and that machine mixing has been tried and gave less satisfactory results. If retained, it should be done at a higher level than the opener, unde a large exhausted canopy and the mixture fed at a series of chutes. Delivery lattices should be well enclosed and exhaust applied, as now done in some cases; otherwise dust is evolved.

Opened material not required at once, may be stored in open bins in the workroom, involving emptying and filling sacks or skips, which necessarily cause dust. This storage in bulk should be avoided; alternative arrangements might be adopted which avoid dust.

Some material, e.g., long fibre waste from later processes, is opened at enclosed lattice-fed teasers or willeys, not infrequently of primitive design, worn out, and emitting much dust, notwithstanding that a fan is an integral part of the machine. These old machines should not be used for asbestos opening. Dust may be emitted at feed points of modern machines, particularly when the feed is irregular. Exhaust is necessary at the feed lattice for this reason and also because feeding itself causes dust. The material is either discharged upon a lattice for immediate collection, or blown into a chamber. The standards suggested for Crighton machines should be adopted.

Hopper lattice feeds are largely used with opening machines; the hopper lips are about 3 feet 6 inches above floor level. Much dust is produced in shovel-feeding as it is difficult to avoid scattering at the lip. An enclosed lattice, fed at or just below floor level, with localised exhaust applied to the enclosure is more satisfactory.

Single disintegrators, or two or three machines in series are used for breaking up textile or other asbestos waste, more rarely for opening crushed asbestos. Present arrangements for preliminary hand sorting of waste are unsatisfactory: it should be accomplished at a covered bench, suitably exhausted. Whereas in some cases, the indraught at the disintegrator feed openings caused by the rapid rotation of the rotor is not sufficient to remove dust, and because, at any rate, as soon as it is stopped, escape of dust may result from reversed air currents, exhaust should be applied here also.

Disintegrated material is blown into chambers, a blower fan being in some cases connected to the delivery of the machine to create a stronger draught. Air pressure in the chamber is relieved in different ways, the sides may be covered with sacking, allowing much dust to escape, a "relief balloon" connected, or exhaust applied. Chambers connected with disintegrating and teasing machines vary in size, some are little more than a large box, others are more roomy. Some, but not all, are separated from the workroom. They are entered for emptying, the material being filled into sacks or skips by hand after the machine is stopped or the flow of material diverted to another chamber. Work in chambers is very dusty and its elimination is most desirable. (See page 26.)

Carding.—Considerable developments have taken place in recent years. One or two important new cardrooms have been started. Many new machines, including some of foreign construction, have been installed.

The machines, of large overall dimensions, are of the roller and clearer type. Modern cards are of high class construction and fitted with two doffer cylinders supported on a carriage, which can be racked into or out of position. For fine yarns, a breaker and a finisher, constituting a set, is used, connected by lattices, lap sliver from the former being automatically fed to the finisher card. In cases where the sliver is collected in cans, a Derby doubler is used for preparing laps for finisher cards.

Single machines and breaker cards are equipped with hopper lattice feeds supplied from skips or sacks, handfuls being dropped in, and shaken apart as fed, or the sack emptied into the hopper. The asbestos falls intermittently upon a creeper feed which conveys it to the "licker-in" feed rollers, between which point and the doffer the material is under enclosed conditions.

The material is combed from the open doffers of finisher cards, as a web or "sheet", the sheets from the two doffers usually being combined at a condenser, and the resulting sliver yarn wound into spools. Occasionally, combed web is collected without being condensed, the condenser carriage being withdrawn. In other carding, the sliver may be obtained as a lap.

Admixture with cotton is usually accomplished by carding the two materials together, a cotton lap being mounted above the creeper feed, and the cotton fed through the feed rollers with the asbestos.

The evolution of dust at cards is inevitable and a fine dust cloud may be observed in most cardrooms. Suppression of dust cannot be realised unless machines are maintained clean and in satisfactory repair, and there is effective enclosure of various parts. Above all, localised exhaust must be applied at well-defined points of dust emission, and improved stripping arrangements provided. Wide spacing of machines is also desirable.

The upper parts of modern machines are usually provided with well made wooden covers and the lower parts are enclosed below in metal. The frames are well enclosed at the sides. A hinged metal cover, fitted in some cases, prevents escape of dust produced by movements of the feed lattice. A curtain of fabric is less satisfactory. In older types, particularly, the wooden covers may not fit satisfactorily, the cylinders may not be truly aligned with the frame and other defects may account for side escape of dust, not controllable by exhaust. Such defects should be remedied. Creeper feeds, doffers and condensers and connecting lattices between breaker and finisher cards are not enclosed. Dust is evolved at doffer combs and at creeper feeds.

Localised exhaust ventilation was first applied to carding machines many years ago. Methods and apparatus have since been gradually improved and more powerful exhaust draughts are now used. One large firm have achieved much success by standardising their practice as regards points of application of exhaust draught, design of air guides, size of branch ducts to air guides and duct velocity. Exhaust is applied at (*a*) the presser at the creeper feed; (*b*) feed roller at licker-in; (*c*) top of cylinder; (*d*) each doffer, air guides or hoods being fitted at these points with connecting branch ducts. Muff couplings, used on branch pipes, facilitate easy dismantling. Branch pipe sizes and duct velocities are liberal. The improvement realised by applying powerful exhaust at each of the points mentioned, at all of which evolution of dust is important, shows that this practice should be followed generally and gives point to the view expressed by some occupiers that carding can be carried on practically dust-free. Apart from the above case, exhaust is applied in nearly all cases to the cylinders; in a moderate proportion to the creeper feed; in a few, to one doffer—the top and in one or two only, to the bottom doffer. But, apart from dust-emitting points not provided for, the results may be inadequate. Carding machines are occasionally installed and put into use without exhaust, this should never be done.

Efficient results are not possible unless the exhaust draught is applied as closely as possible to the dust-producing points. Transverse air guides, with branch ducts connected at each end, are apparently more efficient than pyramidal hoods of the usual type. Ducts of adequate diameter and high duct velocities are essential.

The usual air guide for the cylinder, provided to effect removal of dust both during carding, and stripping and grinding (though proved inadequate for stripping) is placed a little above an opening in the crown of the cover. Two branch ducts, as above, and in addition a larger central branch duct (for use during stripping) are connected to it. The shallow space below the back of the air guide is closed up during carding by a wooden hinged piece—thrown back for stripping—and the dust produced at the cylinder is prevented from escaping by inflow of air from the room, at the front. The dust-laden air is withdrawn at the side ducts. In stripping, inflow of air carrying some of the stripping dust takes place from below the lifted cylinder cover; the central branch duct, kept closed by a blast gate during carding, is then fully opened to provide a greater air volume.

In one factory, a circular doffer cleaning brush runs continuously above the doffer comb. A pyramidal exhaust hood is provided, but much dust escapes; unless fully efficient exhaust is devised an alternative to this cleaning, if really necessary, should be found. The collection of combed web, previously referred to, is done without exhaust and dust is produced. Collection might be effected by exhaust draught as applied for removing side waste at condensers.

Notwithstanding the use of covers for card lattice feeds dusty conditions are produced and exhaust draught should be applied at this point also.

Stripping and Grinding.—Card "stripping" or cleaning is done when the machine is opened out for grinding, which follows cleaning and takes place at each machine about once a week, but shorter and longer intervals also obtain. In one important factory the two processes are combined in one operation. Roller and clearer cards must be opened out, i.e., the lattice feed and breast, and condenser and doffer carriages are drawn back, the cylinder covers are raised, and the various small rollers, which are cleaned and ground at a special machine, removed. The cylinder is first cleaned, with the doffer carriage drawn back; the carriage is then replaced and the doffers, run at a greatly increased speed, cleaned in turn. Cleaning takes about ten minutes and is usually done in working hours, but in one case, at least, after. The men press their "strickles" or flat hand brushes about 12 inches long covered with card clothing, against the wire-covered surfaces. Much of the debris is heavy and falls to the floor. Dust is evolved in a dense cloud, some being removed at the cylinder exhaust hood. In one case floor openings, beneath the machine, are connected to the exhaust. Present exhaust arrangements are altogether inadequate, particularly so as regards the bottom doffer. Much dust is therefore carried into the general atmosphere of the room. The cleaners wear respirators or "helmets."

In a few cases, more effective measures are taken, e.g., the opened-out machine is almost entirely enclosed with high canvas-covered screens. In the works where cleaning takes place after working hours, an auxiliary exhaust system, with a hood for the bottom doffer, is brought into use.

Grinding which takes several hours, is an automatic process effected by abrasive covered rollers driven by the machine. The small amount of dust produced is chiefly of a metallic character.

In the factory where grinding and cleaning are combined, the doffer exhaust arrangements are first re-connected. Much less dust is evolved and appears to be dealt with more effectively. This firm consider that hand strickling before grinding should not be allowed. Their methods may, however, not be generally applicable. A little strickling may be necessary after grinding to remove small pieces of débris.

The trade recognise that present conditions are not satisfactory and experiments are being made with the object of developing improved appliances. In one case a revolving brush is being tried, with independent exhaust draught applied by flexible connections; it is said to give promise of success. The brush is narrower than the hand strickle and less dust is evolved at a particular moment. In another case, a vacuum fitting is under consideration. Previous use of vacuum stripping was given up because of rapid erosion of the metal pipe bends and other parts. Unless effective dust suppression is realised for stripping, all workers, other than strippers, should be excluded while it is in progress and for some time afterwards, and the room well ventilated.

The machine for cleaning and grinding the smaller rollers, which gives rise to much dust, should be fitted with efficient exhaust arrangements—a straightforward matter—and as completely enclosed as practicable to collect the heavier débris, precautions which are not always taken. The machine is either installed in the carding room, or in a room adjoining. Independent machines should be provided to deal with rollers of different lengths, otherwise inconvenient adjustments, liable to be neglected, have to be made.

Card Side Waste Treatment.—The irregular "selvedge" of carded fibre, separated at the two sides of the finishing card, being unsuitable for sliver yarn, is removed by suction draught to a "side-end" machine, which prepares it for further use. The material is blown upon perforated cylinders, the air escaping at the side and the material being discharged on the floor. The process produces dust, particularly when the feeding is irregular, the air then having a free path between the cylinders. The material should be delivered under suction and not under pressure, a "pressure" machine being unsuitable.

Spinning and Doubling.—Yarn is spun at flyer or ring frames which may carry up to 80 spindles, 40 on each side. Much piecing is required owing to the comparative weakness of the fibre. A fine metal thread is spun with asbestos, for brake linings and certain other purposes. Mule spinning is not practised in this country. A large amount of doubling is carried on.

Spinning, more particularly ring spinning, gives rise to dust, continuously produced by the "ballooning" out of the fibre owing to the rapid rotation of the spindles, which may run at speeds of 1,700 revolutions per minute, and intermittently, when the yarn breaks. Doubling is less dusty than spinning. While the amount bears no comparison with that produced in carding, and is less than that from dry weaving, the workers are continuously exposed to some dust, more in some factories than in others, doubtless due to differences in working methods or materials. Exhaust draught for its removal has not been applied hitherto, but experiments in one factory have been so far successful that the firm are prepared to equip all spinning and doubling frames with exhaust ventilation plant, embodying (i) exhaust ducts parallel with the frames, above the tin rollers, with shaped hoods at intervals, each to deal with a small group of spindles, and (ii) for more effective concentration of the draught, panelling for the ends and lower parts of the frames beneath the spindles, capable of being easily removed when necessary. Such safeguards may require somewhat wide application unless special general ventilation is provided.

Warping.—Warp beams are prepared in the usual way from creeling frames, a small evolution of dust occurring at the frames and beaming machines: localised exhaust ventilation could hardly be applied effectively. A partitioned-off space, mechanically ventilated crosswise, with extraction at low level would effect improvement.

Winding.—Many winding machines are used, varying from makeshift types of primitive construction, at which the practice may obtain of holding the yarn in the hand, to modern universal winders for winding "cheeses." Dust may be evolved to some extent, particularly in connection with the above practice, which could be eliminated. Application of exhaust draught will then probably not be necessary, except in particular cases.

Plaiting and Braiding.—Plaiting and braiding, also carried on in engine packing and electric cable factories, and done at machines of normal design, cause some evolution of dust, except where the yarn is impregnated with "grease." While the amount of dust is sometimes less than in spinning, the difference is not material. But there is perhaps less exposure of the operative under ordinary working conditions and precautionary measures other than localised exhaust ventilation may suffice.

Weaving.—Looms vary greatly in size and general arrangement. As many as 140 looms may be found in a single room, but this is exceptional. The clear space between machines may not exceed 18 inches. Some looms are independently driven by electric motors. Cotton warp or weft is sometimes used. Thin cloth, for mattress covers, filters, clothing, etc., is woven from a single warp beam at a simple type of loom. Belting looms, for thick belting and brake lining material are complicated, several warp beams, arranged in tandem under the loom, or in some other convenient way, being required. These looms are narrow, but often very long. Tape looms are also narrow, unless several tapes are woven together when several shuttles, in line, working in unison, are used. Cloth is beamed at the front in the usual way, but belting may be led under the loom and coiled high above it, at the back.

Most weaving is "dry," but some weaving is done wet, either warp or weft, and occasionally both being wetted. Wet weaving is accomplished more easily and a closer weave obtained, but rusting of heald fittings, and the subsequent drying entailed and the less satisfactory appearance of the material are disadvantages. Thoroughly dry fabric is required for brake linings and rubber-proofed material, and wet woven cloth may be strongly objected to on this account.

Considerable evolution of fine dust occurs in dry weaving as a result of (*a*) the forward movement of the slay in "beating up," this source being close to the operative, (*b*) the repeated contacts of the rising and falling warp threads with their neighbours, this source being the most important from a quantitative standpoint, (*c*) the disturbance of "dust" or "fluff" on machine parts, especially those in motion. A fine dust cloud may be observed behind the healds above the warp threads. Much less dust is produced in wet weaving.

Some "dry" looms are now fitted with localised exhaust usually applied to deal with dust evolved by both (*a*) and (*b*), in some cases (*a*) only. (*a*) A flat horizontal "hood" is fitted in front of the operative, just above the cloth, the opening facing towards the healds; (*b*) either an upright pyramidal hood, placed transversely, or horizontal flat hoods, one on each side facing each other, are fitted close behind the healds. The second arrangement is the more effective for narrow looms, as the "scissors-like" action of the warp threads appears to displace most of the dust to the sides. The exhaust draught has effected some improvement, but all the dust is not removed, especially that produced by (*b*). It may be impracticable to apply the draught to all dust-producing points behind the healds, particularly at long looms, but greater success would have been achieved with more powerful draught and larger air displacements, as is now being recognised.

The methods described for dealing with the dust created by (*b*) must be less successful at cloth looms of ordinary width. A few such looms in one factory have recently been equipped with large "bonnet" hoods, fitted transversely, close down over the machine, covering the slay, reed and healds. The hoods are of hemispherical section, with extensions over the shuttle boxes. An internal electric light fitting, and hinged sections, facilitate working. A powerful draught, suitably applied, should prevent escape of dust, generated within. In another case, experiment is said to have shown that a transverse inclined hood facing the operative, placed just below the warp near the front of the loom can be more effective for reducing dust concentration in the air breathed, than present arrangements, and the new design is to be substituted.

Application of efficient dust removal arrangements to weaving is clearly difficult. The expedient of installing individual machines or small groups of machines in suitably ventilated small rooms or cubicles, as suggested under "Warping" does not appear to have been tried, but might be considered if localised arrangements are not sufficiently effective. Long narrow sheds, for a single line of looms, ventilated as suggested, might be a possible alternative

Cloth Picking, Examining, Measuring.—There operations involve running out the rolls of cloth and tend to produce a small amount of dust. If carefully done, so that very little dust is created, other precautions may be unnecessary

NON-TEXTILES.

Fiberized asbestos is not used in some of the non-textile factories and exposure to asbestos dust may be slight or even negligible. Dust is evolved in factories or departments where such material is prepared for subsequent use, or for sale, and also in departments where fiberized material or dry mixtures containing it are manipulated in preliminary manufacturing processes. Again, finishing processes, involving abrading or cutting at high speed, may be a source of dust, but such dust may contain only a small percentage of asbestos. The application of exhaust draught, where suggested in the following description of processes, is in most cases a straightforward problem, comparable with many others met with in non-textile factories, e.g., woodworking and grinding, where machinery similar to that described is used.

Fiberizing or Opening.—Fiberizing is almost exclusively confined to works in groups (*b*) and (*c*). Much of the work is done under less supervision than in textile factories and unsatisfactory machinery is more common. Primitive teasers ("devils") are used in several mattress-making works, and chamber work is also an unsatisfactory feature (see p. 22).

In some asbestos-cement sheet factories, crushed material, from edge runners, falls into worm conveyors below, which transfer it automatically to disintegrators. In one large works, the process is being entirely enclosed; the material from the edge runners, which are lattice-fed, will be discharged upon a conveyor and raised by an elevator to large overhead storage hoppers, fitted with automatic bagging lattices. Localised exhaust draught will be applied at feeding and delivery points, where dust might escape.

Chambers have been eliminated in some large works, with beneficial results. The material, after being disintegrated or opened, is fan-handled, and blown to a hopper fitted with bottom rotary delivery valves, the air being re-circulated. The material is bagged at lattices. Direct supply to a manufacturing point is another improvement now being tried. Such pneumatic conveyance should be practicable in many cases. Localised exhaust at feeding and discharge points of these systems is necessary. Vacuum methods for filling sacks may also be practicable.

If chambers are retained, the necessity for entering them might be avoided, by providing chambers of small front to back dimensions fitted with low doors, at which sack filling would be done, localised exhaust ventilation being applied over the doors.

(b) Millboard, Paper, Sheets and Tiles.

The wet mixtures for millboard, paper, and asbestos-cement products are prepared in a beater, as used in paper mills. Dry fiberized asbestos is emptied into the beater trough, the sacks being shaken to some extent. Evolution of dust occurs before the material becomes mixed with the circulating water. Occasionally a sack is emptied before the water is turned on. Several sacks are required for a charge and the process is repeated a number of times daily. Precautions are not taken at present but the dust might be avoided by (*a*) mechanical feeding under enclosed conditions, as appears to be done in some foreign works, (*b*) applying exhaust draught, (*c*) feeding in small quantities and in such a way that the material is wetted at once.

Finishing processes on asbestos-cement sheets include sawing to size, corrugating, pressing and drilling, carried on in some factories with the material so moist as to prevent dust, and this practice should be adopted generally

Otherwise much dust is produced in sawing, owing to the rapid cutting speed, and localised exhaust is necessary though not applied. Similarly, turning, filing and smoothing of dry asbestos-cement pipes, at lathes, may require exhaust to remove the dust produced.

Synthetic composition sheeting, sometimes made in a rubber department, is produced from dough consisting of fiberized asbestos and rubber, mixed with solvent in kneading machines. Dust is produced in feeding the mixer with asbestos, done in an open manner by hand, from sacks or skips, the sacks being shaken out, or from an open lattice feed. Subsequent processes are dust-free. Exhaust should be applied at the feeding point.

(c) Insulation Materials and Articles.

Compositions.—" Magnesia," the most important insulating composition, is produced on a large scale by the principal manufacturers, by enclosed methods with pneumatic conveyance of the mixture to automatic sack fillers. Weighing and feeding the fiberized asbestos gives rise to dust for which exhaust is necessary.

Fiberized asbestos or " magnesia " is a component of many insulating compositions which may also contain clay, kieselguhr, fossil meal, flax, hemp or jute waste and other materials. The proportion of asbestos in the final product varies widely. In many small works the materials are mixed " dry," by hand, in an open manner, involving sack emptying and filling, shovelling and weighing. Enclosed rotary mixers could apparently be used for such work with exhaust applied at feeding points and the material discharged and bagged under enclosed conditions. If hand work is retained, exhaust should be applied.

Consolidated Sheets.—Large sheets resembling thick mats, built up of layers of fiberized asbestos, are consolidated with silicate of soda, sprayed on in manufacture. The sheets may be backed on one face with millboard, or supplied without a backing, being faced when fixed with millboard or asbestos-cement sheets.

The sheets are produced of the required size and shape at work benches, or built up on the table of a machine, capable of slow reciprocating movement, and fed from a hopper above. In the former case, the fiberized material is taken in handfuls from skips and spread out in the forms, the surplus being scraped away and falling about at the sides of the work benches, and on the floors, a considerable quantity being scattered. Dust, produced in manipulating the dry fibre, before treatment with the silicate of soda, is largely avoided at the machine. Efficient localised exhaust should be applied to the hand process with improved bench arrangements, to prevent scattering.

Band sawing of piled sheets, causes evolution of much dust, owing to the considerable depth of cut. Localised exhaust alone, not yet applied, may prove insufficient.

Sections and Slabs.—Moulded insulation is made chiefly in two forms, sections—semi-cylindrical and moulded hollow to suit various pipe sizes—and slabs, which are rectangular and solid. These products are usually moulded wet, either by hand or machinery, from a paste or cream, prepared in a mixing machine or tank. Feeding of dry material involves evolution of dust which might be avoided by one of the methods suggested for feeding beaters in millboard making.

Sections are made at one factory by a dry process, at a machine indifferently enclosed. Feed hoppers, filled from skips, deliver the asbestos to internal lattices which in turn supply a travelling band, at which the section is rolled by hand. Revolving brushes which clear the lattice and spread the material evenly on the band give rise to much dust, and dust is produced at the hoppers, and in rolling and brushing away superfluous material. Exhaust draught, not hitherto applied, is to be provided at the exposed brush and the machine is to be more effectively enclosed. An enclosed " feed " is also necessary.

The sections and slabs are trimmed to size with circular or band saws. Much dust is produced and exhaust draught is commonly applied, but is in some cases inefficient. Circular saws used in some cases in pairs, for trimming ends in one operation, can be fitted with exhaust hoods above and below the benches.

and band saws can be enclosed below the tables and inverted hoods fitted, the exhaust draught being applied as for woodworking machines. Efficient arrangements should be readily practicable for all sawing work here.

Mattresses.—Mattresses are manufactured by practically all firms who produce insulation requisites, though only occasionally by some. Mattresses for large contracts are made in the contractors' premises, their outdoor staff taking necessary measurements and preparing rough plans. A mattress has sometimes to be made on site.

Mattress making involves, broadly speaking, the sequence of processes associated with the making of domestic mattresses. The work is almost entirely hand work. Lengths of asbestos cloth for covers are cut out on a wide bench and sewn up, by treadle or power driven machines, to an extent depending on the method of filling. Large mattresses may be sewn along one side only or both sides may be seamed and filling done from both ends. Before filling, covers are turned inside out. Supplies of filling material, which usually, but may not, contain fiberized asbestos, are brought, in sacks or skips, from chambers, or taken from open bins, in the room, kept supplied from the chambers, or from sacks of material supplied by outside firms. Filling is done by hand, scoop or shovel, and quantities may be weighed. The end filling of long double-seamed mattresses, referred to above, necessitates the workmen mounting on the bench to empty the material from skips into the openings. After filling, the mattress is levelled or beaten, to make the filling lie evenly within, the hand or a flat wooden beater being used. Finishing processes include final sewing, stubbing or buttoning, fixing on hooks, etc.

Some dust is produced at the cutting out bench, in opening out the roll of cloth, and at the sewing machine, but far more in taking material from bins or sacks, in weighing, filling and levelling. Beating of the cloth produces asbestos dust, the amount of which is largely increased if the filling contains asbestos. The work is largely done without regard to the necessity for suppressing dust. All benches are entirely open. Localised exhaust draught is not applied.

One firm have improved conditions considerably by the following precautions:—

(*a*) Keeping floors and benches damp and spraying covers before filling. Hose connections and spray fittings are provided.

(*b*) Sub-division of department into several independent workrooms.

(*c*) Exclusion during filling of all workers not so employed, the excluded workers proceeding to another section.

(*d*) Mechanical ventilation of each room by cross ventilation, embodying plenum supply (warmed when necessary) at one side and low level extraction at the opposite side, the air being changed between 10 and 20 times per hour.

(*e*) Enforcement of use, by fillers, of respirators.

These precautions do not include application of localised exhaust ventilation, without which mattress filling and beating must involve some risk of inhalation of dust. For small mattresses, a wide double-sided canopied bench with exhaust draught applied at gratings along the centre line might be used, the filling material being supplied within the canopy. Such a bench may not perhaps be practicable for the making of large mattresses but the possibility should be explored. Otherwise at least the precautions referred to above should be adopted.

(d) Brake and Clutch Linings.

Before being impregnated, the dry asbestos cloth, known as "grey," may be calendered at squaring rolls and in all cases the coils are cased out to separate them a little, so ensuring thorough treatment by the liquid. A little dust is produced in these operations but insufficient to render special precautionary measures necessary. Other preparatory work on "grey" arises in the making of special linings. Lengths of cloth are lightly hammered to ring shape, in templates, then cut with chisel or shears and the radial edges sewn together at a wire-stitching machine, as used in book-binding. Dust occurs in hammering and stitching. A canopied bench fitted with localised exhaust arrangements might be provided and the machine placed under exhaust draught.

Dry impregnated material is shaped and finished mainly by power-driven machines, e.g. knives, circular and guillotine, cutting presses, hydraulic squeezing presses and band saws. Cutting and sawing expose ends of wire and leave rough edges, trimming and smoothing, done on grinding wheels and linishers, are necessary to obtain exact size and finish. All the operations, except squeezing, produce waste, and dust is created in some. The dust is heavy and sticky and less likely to fly about than dry asbestos dust. The amount is considerable at sawing and grinding machines and localised exhaust draught, to remove it, has been applied—in some cases with much success—and is always necessary.

Inverted hoods are fitted at band saws, just below the tables, the dust being drawn through the small openings in the table guides. A powerful draught is essential.

Grinding and finishing wheels include, in addition to ordinary single-disc machines, two-disc and vertical spindle segmental grinders, used for flat linings. The hoods by which the draught is applied to all these types are similar to those applied to the same machines when used for metal grinding. The position is similar as regards linishers, a hood being fitted in line with and at the back of the band. A baffle plate to prevent dust being carried past the hood by the high linear speed of the band is a necessary addition.

Special linings and anti-friction bushes are moulded from disintegrated impregnated waste. Some dust is created in the filling of moulds and efficient localised exhaust draught may be necessary. The articles are shaped and finished as just described. Bushes are turned and bored in lathes, with production of waste and dust, but exhaust draught is not at present applied though possibly necessary.

(e) Packing and Jointings.

Engine packing is either (*a*) " cloth " packing built up from cloth, usually rubber proofed on both sides, handling of which does not cause dust, and (*b*) " rope " packing made from yarn, at braiding and plaiting machinery, as used in textile factories. (*a*) Negligible amounts of dust may arise at the spreading machine, from the unproofed cloth, and, in building up, from material proofed on one side only. (*b*) " Cheeses " of yarn are first rewound on bobbins for the braiding and plaiting machines. Simple winding mechanisms are used. Some little dust is produced; special preventive measures will usually not be necessary.

Flat packing, known as " grummet," is made, on a small scale, from asbestos yarn, threaded on a needle and wound in and out by hand, as balls of wool are wound. This apparently insignificant process causes sufficient dust to cover in a short time the hair and clothing of the workers and should be done at a canopied bench provided with localised exhaust arrangements.

(f) Asbestos-covered Electric Conductors.

Electrodes.—Electrodes are either wrapped with yarn, the usual method, or passed through paste containing asbestos fibre, yarn being wrapped upon this coating. The former method is usually achieved by a small high speed stranding machine fitted with a flier carrying the spools or bobbins of yarn, the wire travelling axially through the flier. Treatment with consolidating liquid, straightening and cutting to length follow, all done at the stranding machine. Alternatively, single electrodes may be wrapped by a simple winding mechanism, hand-operated or power-driven. Paste-covered electrodes are also made singly at small extruding machines, a flier for feeding the yarn being fitted behind the extruder.

After drying, a short length of the covering at one end is ground away, leaving the bare metal necessary for making electrical contact in the holder, when in use. Small abrasive wheels, almost entirely enclosed, are used.

Small amounts of dust are projected from fliers, though insufficient probably to require the adoption of special precautions. Much dust is produced in grinding ends and efficient exhaust ventilation is essential; present apparatus, where provided, is capable of improvement. The process would be unnecessary if bared ends were left in manufacture, and experiments directed to this desirable end are being made and give promise of success.

Preparatory processes in paste making include (i) dry grinding of fiberized asbestos by small vertical disc grinding wheels, fed at the centre from a hopper above and discharged from the periphery into a box below, and (ii) hand mixing of the ground materials at a bench, involving emptying out of dry material into pans. Dust is produced, the amount being considerable in grinding. Little precaution is taken. The processes might be accomplished under almost entirely enclosed conditions, efficient exhaust draught being applied at points where dry material is exposed, e.g., in feeding.

Rewinding of yarn is sometimes necessary and primitive arrangements may be used, the practice referred to on page 24 being followed, and as a considerable amount of dust is produced, the practice should be given up.

Cable and Wiring.—Asbestos-covered cable and wiring constitute a small percentage of the output of the cable factories. The yarn is braided and plaited on the conductors at machines, not reserved for "asbestos" products, similar to those previously described. Rewinding of "cheeses," as received from asbestos textile factories, is done at universal winding machines. The amount of dust evolved is small, and special precautionary measures are apparently not required.

Field-coil Wrapping.—Field coils for electrical machinery are wound with asbestos tape by hand at ordinary work benches. The process does not give rise to appreciable quantities of dust.

(g) Miscellaneous.

Moulded Goods.—Some electrical insulating fittings are moulded from varnish-impregnated fiberized asbestos, prepared after thorough drying in a mixer and ground in an edge runner. Alternatively, impregnated scrap, ground in a rumbler, may be used. The preparatory processes on dry or practically dry material are intermittent, and involve sack emptying, shovelling, weighing, filling and emptying shallow trays. They are carried on in an open manner without special precautions except that as regards grinding, hanging curtains may be used at the edge runner, and the scrap rumbler is enclosed. Dust is evolved in the processes mentioned and localised exhaust ventilation should be applied to effect its removal, with, in addition, effective enclosure of some hand work, e.g., emptying of trays into machines could be done inside a cabinet provided with internal arrangements for securing the trays and an external handle for turning them over. Localised exhaust may be necessary for final trimming if done at abrading wheels.

Moulded articles made in other trades may contain but a small proportion of asbestos, although a large quantity may be used. In one case the asbestos is sieved after drying, both operations being done in enclosed machines, and, in addition, dry mixing, done in rotary machines, and paste mixing, on open rolls, as in rubber works, are also required. Processes carried on with some risk of exposure to dust include emptying of sacks into bins, filling of trays for drying, feeding at the sieve elevator hoppers, the dry mixer, and the rolls. Localised exhaust is applied at (*a*) the elevator hopper, (*b*) the storage chamber above an intermediate bagging point, (*c*) the dry mixer, and (*d*) the rolls. More efficient arrangements appear to be desirable for (*a*) and (*c*); the feeding of the elevator might be done under enclosed conditions if a cabinet as mentioned above were provided into which the trays could be inserted. Localised exhaust is necessary at storage bins. Final trimming of rough edges is done under efficient exhaust draught.

Other processes of comparatively minor importance, e.g., asbestos putty mixing, in which there is handing and feeding of dry material in preparatory processes, will call for precautions as previously described for similar work.

4.—Sacks.

In a few cases sacks of sailcloth or other closely woven material are used inside the factories. Such sacks are much to be preferred to those made of the ordinary material, which is "leaky" and gives rise to dust in handling.

5.—Cleaning of Works, Machinery and Sacks.

Some factories are kept in a more cleanly state than others, but higher standards and improved methods are desirable generally. Weekly cleaning by dry methods is general in textile factories, but is more effectively done in some cases than in others. Casual cleaning may also be done during the week. The dust which gathers in a week renders cleaning a very dusty operation. Young workers may be seen on carding machines brushing dust into the air from the covers, etc., in considerable amount, near other workers. Some firms have instituted more frequent regular cleanings and more satisfactory methods by damping before sweeping.

Vacuum cleaning methods have not been adopted and such methods seem to be regarded as impracticable, but this can hardly be accepted. Portable vacuum sets are constantly used with great advantage in other classes of works, e.g., electric cable factories, by adult cleaners who keep the machines, plant, service pipes, etc., thoroughly clean.

If vacuum methods are not adopted, well organised daily cleaning, by adults using damp methods for floor cleaning, should be the rule in textile factories. A water supply with suitable hose and spray connections should be provided.

Débris produced in asbestos-cement sheet works under moist conditions may become dry and cause general dusty conditions. Cleaning should be so frequently done as to prevent this.

The cleaning under machines such as looms and cards entails collecting waste of considerable value, done at present by hand. Vacuum collection should be possible: in principle, it is already used for removing side waste at finishing cards. The sound principle of collecting card waste, through floor openings, has been adopted in one new factory, and might be followed in others, with automatic collecting arrangements.

Sack cleaning is done in a few large works in enclosed machines, involving some risk of exposure to dust in filling and emptying, notwithstanding the provision of localised exhaust ventilation. A type of "exhausted" machine which does not involve such work is to be preferred.

6.—Summary and Recommendations.

Asbestos factories and workshops cover a great variety of processes. The premises differ widely in structural features and are congested in many cases with machinery or material. Processes are largely carried on in close association.

Dust is produced at many kinds of machines, in hand process work, and in simple incidental operations, particularly in emptying settling chambers, and in all handling of "fiberized" asbestos.

In textile factories, pure asbestos dust is continuously produced, in differing amounts, at all the principal machines. Card stripping, a very dusty operation, is usually effected by hand strickles. Hand mixing of different grades and varieties, incidental to opening processes, is also dusty.

In non-textile factories, pure asbestos dust is produced at opening machines, in feeding machines, in making insulating mattresses (a dusty hand process), and in incidental hand work. Dust, though rarely pure asbestos, is produced in finishing operations, e.g., sawing, grinding and other abrading of asbestos products.

The appropriate methods for suppression of dust may only be fully determined when the harmful effects of comparatively low concentrations of asbestos dust are duly appreciated. Very dusty processes will not fail to be recognised, but in processes such as spinning and weaving, in which in other textile trades special methods for dust control are not required, due precautions are also necessary. The asbestos manufacturers are clearly confronted with the necessity of attaining conditions in their industry which will ensure much less dust in the atmosphere than can safely be tolerated in many comparable trades not using asbestos.

The principal methods for the control of dust are:—

(*a*) application of exhaust draught at dust-producing points;

(*b*) substitution of enclosed mechanical methods for hand conveyance and for dusty hand work generally;

(*c*) effective enclosure of dust-producing machines and plant;

(*d*) substitution of wet methods for dry.

Each of these has its particular sphere of utility, and the particular indications for their adoption are put forward *inter alia* in the recomendations below.

RECOMMENDATIONS.

(1) Application of Efficient Localised Exhaust Ventilation at dust-producing points.

This measure, of the greatest importance where manufacturing and incidental processes occasion escape of dust not controlled by enclosure or other measures, is necessary for :—

(a) *Dust-producing machines*, e.g.—

(i) Crushing, disintegrating, teasing and other opening machines; sieving machines; fibre grinding machines; dry mixing machines; rolls fed with dry mixings.

(ii) Carding machines (to suppress dust from cylinder and doffers, caused by stripping and grinding, in addition to that produced by carding); card side waste exhaust machines; looms for dry weaving; stripping and grinding machines; other textile machines, if the dust evolved renders this preventive measure necessary.

(iii) Sawing, grinding, trimming, polishing and other abrading machines, used on dry asbestos products.

(*b*) Feeding and delivery lattices, or other conveyors, at machines or other plant; feed hoppers at elevators; bagging lattices; feeding of dry material at wet mixing machines.

(*c*) Chambers, containers, "cyclone" hoppers, or other enclosed space into which fiberized asbestos or mixtures containing it are delivered, or pass.

(*d*) Work benches, e.g. for mattress making, waste sorting.

(*e*) Various hand operations, e.g., sack emptying and filling, weighing, mixing.

This is the principal measure hitherto adopted, and is probably that most generally applicable. It has been applied to some only of the above machines, and appliances, but not to hand work. The methods of applying the exhaust draught, and other associated factors, are becoming more effective, but there are few fully satisfactory plants. Special difficulties remain to be overcome in some cases, e.g., looms, mixing, mattress making. If not surmounted, an alternative, viz., general ventilation of a high standard applied so as to draw the dust-laden air away from the worker, should be provided.

(2) Substitution of enclosed mechanical methods for hand conveyance, and for dusty hand work generally.

This measure—

(*a*) avoids depositing material in chambers, intermediate filling and emptying of sacks or skips, hand feeding of machines, and other incidental hand work;

(*b*) permits of final filling and weighing, under the least dusty conditions, of materials for dispatch;

(*c*) renders exhaust draught more effective, or, in some cases, unnecessary.

It is already employed to some extent, and its further application, wherever possible, is greatly to be desired.

(3) Effective enclosure of dust-producing machines and plant.

(*a*) To prevent escape of dust not controlled by exhaust draught, or

(*b*) to render its application more efficient.

(4) Substitution of wet methods for dry.

To reduce the dust given off in certain processes and work, e.g.,

(a) a considerable amount of weaving;

(b) mattress making, by wetting the covers before filling, and by frequent wetting of floors and benches;

(c) final sawing, and other machine processes, in asbestos-cement sheet and tile factories, before the prepared material has had time to dry;

(d) works' cleaning, by damping floors and benches, before brushing or sweeping.

This measure might be adopted to a greater extent than at present.

(5) Elimination of certain dust-producing appliances.

Certain appliances are used in a few works, sometimes with a measure of precaution, but which emit much dust, difficult or impossible to control by efficient enclosure or exhaust draught. They should not be retained unless effectively modified.

(a) exposed doffer brush at carding machines;

(b) card side waste exhaust machines, delivering under pressure;

(c) certain willeys and teasers, particularly old machines.

(6) Abandonment of Settling Chambers in Manufacturing Processes, to the utmost extent.

(7) Effectual separation of processes to prevent unnecessary exposure to dust.

New factories should be laid out so as to avoid exposing workers to risk from processes upon which they are not engaged. In particular, there should be effectual separation of—

(a) opening, carding and weaving, from each other, and from any other process;

(b) spinning, doubling, plaiting and similar processes, from work not causing dust;

(c) mattress making, from all other work;

(d) chambers, containing fiberized asbestos in bulk, and dust settling chambers and apparatus, from any workroom.

The separation of mattress making should be adopted in existing works, and other separation referred to, as far as practicable.

(8) Wide spacing of dust-producing machines in new factories and, as far as practicable, in existing works.

This measure would bring about permanent reduction of dust concentration in the air of the workroom as a whole, and provide improved cleaning facilities

(9) Use of sacks of close texture material for internal work.

(10) Efficient cleaning system with wide use of vacuum methods. (See also (4).)

(11) Storage of asbestos and other goods to be outside workrooms.

(12) Exclusion of young persons from specially dusty work.

Note.—Particular preventive measures of a medical nature are referred to in Part I, where also the limited value of respirators as a safeguard in this industry is briefly discussed.

Note on Exhaust Ventilation in Asbestos Works.

Some exhaust plants are carefully designed and reasonably efficient, but some are ill-designed and inefficient; others, again, do not effect removal of dust to a sufficient extent. The draught may not be applied as closely as possible to the dust-producing points, or may be too weak. The emission of a visible dust cloud at a point where exhaust is applied is a clear indication of inadequacy.

Extensive alterations of existing plants may produce serious loss of efficiency. Exhaust provision for new machinery and processes should, therefore, generally speaking, be made independently. While advantages result from dealing with many dust-producing points, by a single exhaust plant, a number of self-contained plants, with independent fans and settling apparatus, is often more effective.

Exhaust ventilation applied on a large scale entails continuous removal of a considerable volume of air from the room. The supply of fresh air must be ample or the efficiency of the exhaust ventilation may be reduced. In winter, the workers are liable to bring about this result by closing windows and doors. Plenum ventilation capable of supplying the volume extracted, the incoming air being warmed, may therefore be desirable, where extensive exhaust plants are installed.

Efficiency of an exhaust ventilation plant may be greatly reduced by inefficient dust-settling methods. Each fan should discharge into an independent settler. Settlers adopted in asbestos works include cyclones, large chambers connected with cyclones, large chambers enclosed with sacking or other filtering material, and bag filters. Cyclones and chambers are usually well separated from workrooms. Bag filters are now being commonly adopted, for small installations. These filters and "balloons" are sometimes placed inside workrooms, a bad practice. They are best placed in freely ventilated rooms, effectively separated from workrooms.

Filtering fabrics for settling dust gradually become clogged; and as this effect increases the exhaust plant becomes more and more inefficient, the volume of air moved by the fan being reduced. Such settlers must therefore be kept clean. The usual practice is to beat the filtering material. Arrangements for shaking bags from outside, or automatic shaking apparatus are not provided. Asbestos dust does not appear to be so difficult to detach from suitable filtering material as some dusts, but much dust is produced in beating. Efficient shaking arrangements, avoiding this exposure, should be provided if this method of settling is retained. Some firms strongly support the view that it should be given up because of the difficulty of maintaining the exhaust plant at the highest efficiency. The matter merits careful consideration. In particular, the efficiency of the exhaust plant should be kept under constant observation by a responsible person.

Cyclones should be of adequate dimensions. The combination of chamber and cyclone is used extensively, the fan discharging the air into the chamber, to which the cyclone inlet is connected. The efficiency of this arrangement should remain practically constant.

E. R. A. MEREWETHER.
CHAS. W. PRICE.

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