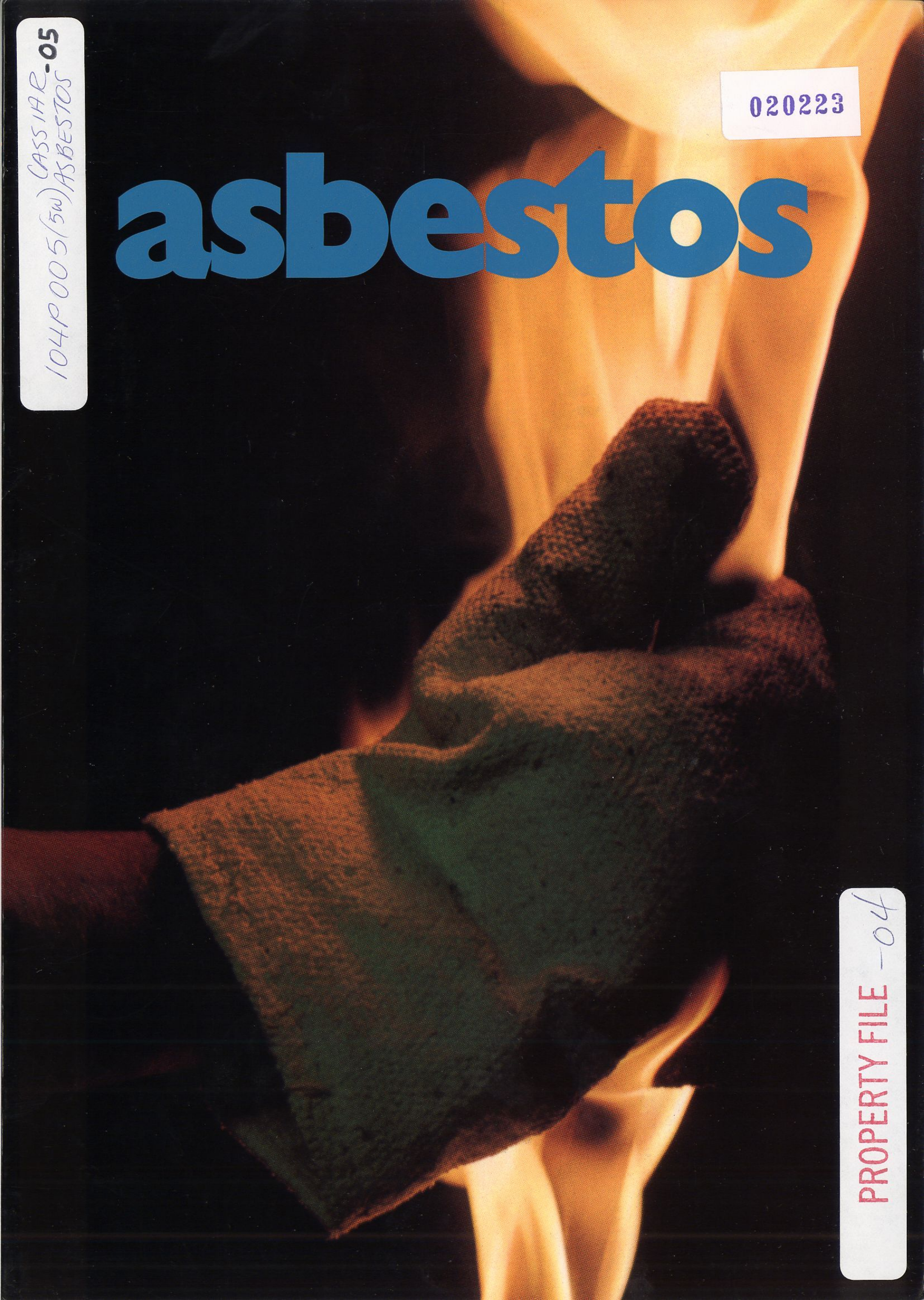
asbestos



asbestos

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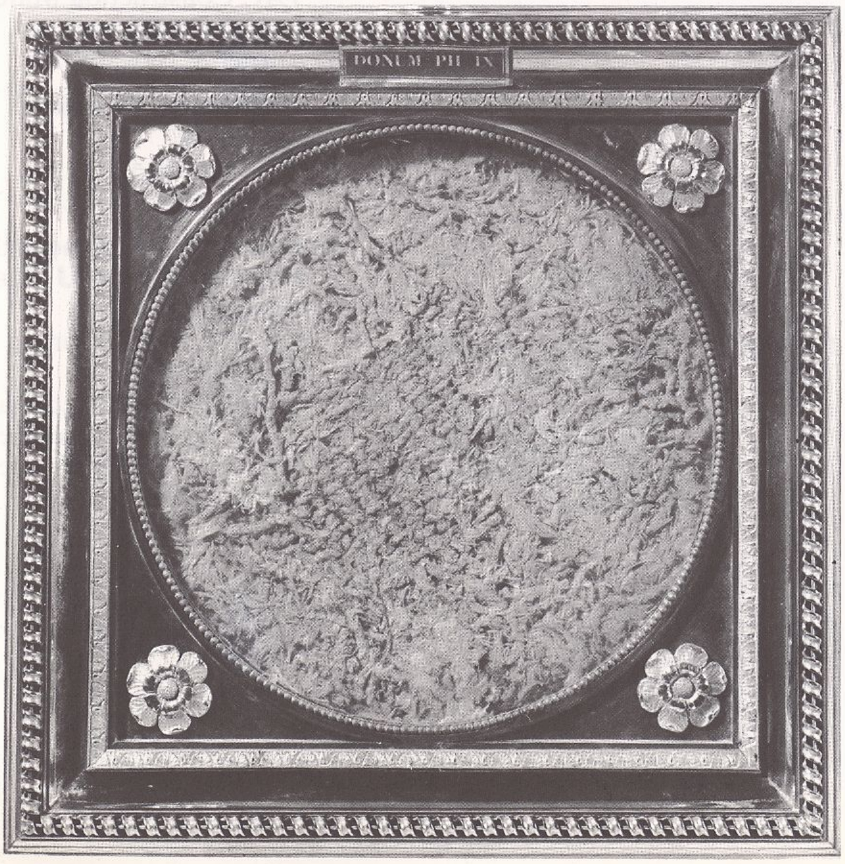
Feature

Some 4 million tons of asbestos are produced every year. The search for new deposits and for more rational, time-saving processing possibilities never ceases, a fact which ensures that this naturally occurring, inorganic fibre acquires wider and ever more varied fields of application. Some of the most characteristic ones are asbestos cement, friction materials, floorings and asbestos textiles.

Cover: Onorio Mansutti

1
The solid green mass of chrysotile fibre breaks up into a "web" of white fibres. If what appear to be single fibres were further opened up, the ultimate single fibres would have a dimaeter in the region of one millionth of an inch.
Photo: Derek Allen, Davyhulme.



2
Part of an asbestos cremation cloth, found in an ancient tomb on the Via Praenestina in Rome in 1702.
Photo: Biblioteca Apostolica Vaticana, Museo Profano, Rome.

Nature and history

by J. Zussmann

Asbestos is the name given to a mineral which is made up of fine fibres and which is resistant to high temperatures. Many minerals are thermally stable but few are fibrous, and of the latter, some have fibres which are coarse or brittle. Many substances of animal or vegetable origin are fibrous, but these decompose readily or even burn on heating. Asbestos is thus unusual in being both fibrous and thermally stable. Moreover its fibres are very flexible and have a high tensile strength; they provide good electrical, thermal and acoustic insulation, and are to varying degrees resistant to corrosion. The combination of all these properties makes asbestos a substance which finds application in a wide variety of materials for industries and domestic use.

The three most important kinds of asbestos are *chrysotile, crocidolite* and *amosite*. Chrysotile is a member of the serpentine group of minerals; it occurs in yellowish or greenish white fibres which are often extremely smooth and silky in appearance and to the touch. Crocidolite belongs to a different mineral group the amphiboles, and it is a blue fibre which is less silky than chrysotile. Amosite, another amphibole mineral, has white or yellowish brown fibres which are rather more brittle than the former two varieties of asbestos. Three less common amphibole asbestos minerals are *anthophyllite, tremolite* and *actinolite*.

History

The name asbestos is sometimes stated incorrectly to mean incombustible, whereas its true derivation is from the Greek word

meaning inextinguishable, paradoxically, since something which does not burn can hardly be said to be inextinguishable. There seems little doubt that the material referred to in this way by the Classical writers (e.g. Strabo[1], Pliny[2], Discorides[3], Plutarch[4] and Pausanias[5]) was one of the asbestiform minerals although it was thought by some to be of animal or vegetable origin. For example, Pliny wrote of the down of a plant used to weave fireproof cloth and Pausanias mentioned lamps filled once a year in which the wick was made of "Carpasian linen" (from Carpasius in Cyprus). The word inextinguishable was probably applied originally to the flames of ancient temple lamps which were kept replenished with oil and thus never extinguished.

An alternative description for asbestos, *amiantus*, meaning "undefiled" has lent itself to the present day French word for the same material, *amiante*. Here the allusion may be to its being generally unaffected by heat, but it may more specifically arise from the use of asbestos in making "cremation cloth". Pliny (*36*, 31, 139) referred to it as a rare and costly cloth, the funeral dress of kings. It was "undefiled" in a special sense, since it was whitened and cleansed by the fire, and served to contain the royal ashes and prevent their mingling with anything outside the shroud. This practice is recorded also (Plot[6]) as being the custom in Tartary in the 17th century.

The early uses of asbestos for lamp wicks probably involved an untreated bundle of natural fibre; the use of cloth, however, implies the weaving of asbestos, although there is evidence that a mixture with vegetable fibre was used. Surprisingly, the use of asbestos for acoustic insulation was also referred to by Pliny*.

After Roman times there are recurring but sporadic references to asbestos, including that by Marco Polo[7] after his travels in Eastern Siberia (approx. 1250 AD), who wrote of a magical cloth that withstood fire (fig. 5). Marco Polo and some of the later writers recognised the mineral nature of asbestos, but others persisted in describing it as vegetable or animal in origin. In the latter category the salamander seems to have been the favoured animal since it had featured in legends as being able to withstand fire; asbestos was referred to as "salamander wool".

A fascinating discourse on the history, nature and uses of asbestos was published by Dr. Robert Plot[6] after a piece of asbestos cloth had been presented to the Royal Society by a London merchant, Nicholas Waite. The specimen was said to have originated in China. Plot, in his discourse, gave an account of how the asbestos was probably treated in order to produce thread and subsequently cloth. Other accounts of asbestos and the manufacture of fireproof fabric appeared in scientific publications at about this time (figs.3 and 4).

Among the Greco-Roman sources of asbestos were Cyprus, Greece, the Ural mountains and the Italian Alps. The Urals and the Alps were also the locations of early commercial exploitation of asbestos.

Early in the 18th century asbestos was re-discovered in the Urals and several decades later a factory was set up near Naviansky, but this did not develop, presumably because there were so few known uses for asbestos at the time.

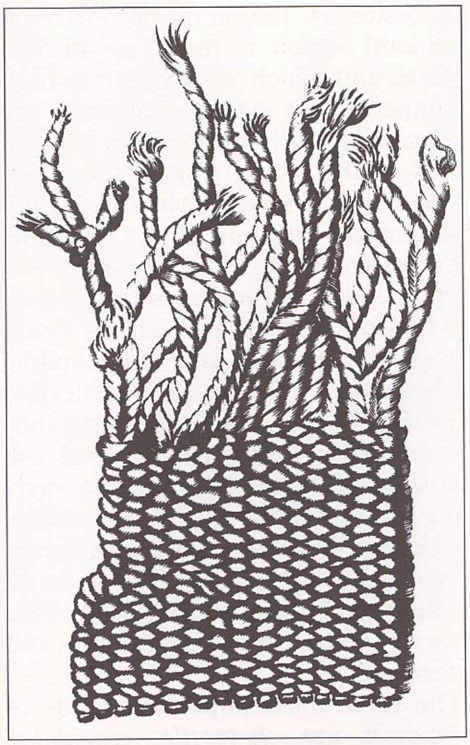
The amphibole asbestos tremolite was discovered and exploited in the Val d'Aosta region of the Alps in 1860. It was then that the word asbestos was first used as a mineral name. The name *tremolite* did not appear until later.**

It was probably applied to the deposits discovered at well-known sites in the Campolungo region. Since no tremolite has ever been found in Val Tremola, this choice of name appears to be another of those classical instances where the actual site of discovery of a mineral is concealed by the use of a completely misleading name.

* "Anaxilaus states that if the linen is wrapped around a tree it can be felled without blows being heard as it deadens sound" (Pliny, Nat. Hist. *19*, 19).

** Editor's note.

3
Woodcut from "Historia Naturale" by Ferrante Imperato, Venice 1672, showing the use of asbestos in the manufacture of fireproof fabric.



4
Illustration of the weaving of asbestos cloth from a treatise by Dr. R. Plot, 1686.
Photo: Bodleian Library, Oxford.

5
A futile attempt at execution: The condemned man dressed in asbestos will not catch fire! An illustration from Marco Polo's account of his journey through the Chinese Empire: 14th century manuscript.
Photo: The National Library, Paris.

At this time, the supply of asbestos was by no means plentiful, and the possible uses were still rather limited. In 1877, however, came the discovery of extensive chrysotile asbestos deposits in the Thetford and Coleraine regions of the province of Quebec, which marked the real beginning of the asbestos industry. With the successful exploitation of the Canadian deposits came further working of the more limited deposits in Italy and Cyprus (chrysotile), and extensive developments in Russia. Also, the search for new deposits received considerable stimulus.

The occurrence of blue asbestos, crocidolite, in Cape Province, South Africa, was recorded early in the 19th century, but large scale mining began only in 1893. Amosite was discovered in the Transvaal in 1907; it was named after the initial letters of the company concerned in its development: Asbestos Mines of South Africa. Chrysotile from Rhodesia was first extracted commercially in 1908.

The uses of asbestos

The first recorded uses of asbestos were those mentioned in Classical writings, for lamp wicks and cremation cloths, but these were somewhat esoteric uses of a rare commodity by a very restricted aristocracy. The cloths and napkins referred to later in Western literature were rare showpieces like the specimen exhibited to the Royal Society of London in 1685. Thus, asbestos was a curiosity rather than a commodity for everyday life. Perhaps halfway between curiosity and commodity was the recorded use of asbestos by a Professor Bruckmann, early in the 18th century, who had some of his writings printed on asbestos paper so that they would be indestructible.

The first commercial venture in the use of asbestos was at the Naviansky factory in Russia which is recorded as having made asbestos gloves, socks and handbags. More successful commercial use of asbestos came with the exploitation in the Italian Alps of tremolite from which asbestos fabrics, string and paper were produced. Greater incentive to the discovery and exploitation of asbestos came, however, with the need for heat insulating packing material that arose with the development of the steam engine. This involved such fabrications as rope packings, insulating boards and boiler covers. Spinning and weaving techniques which could deal with asbestos were gradually improved, and the finer chrysotile asbestos was discovered in larger quantities, so that a larger range of woven goods emerged, including many items of protective clothing.

Another major advance in the use of asbestos came with the development of the motor car, and the consequent need for brake lining materials.

Although for some purposes a pure asbestos product was required, the history of its use is also one of the discovery of new ways in which it could be blended with other materials. For weaving purposes, other textile or metal fibres can be admixed, and in other uses many silicate or non-silicate minerals or mixtures can be added. In the more recent phase of the asbestos industry there has developed the widespread use of asbestos-cement, and asbestos-resin, asbestos-plastic and asbestos-rubber mixtures described later in this series of articles.

Today, many new moulded and extruded asbestos-cement articles are produced and attention is being given to improvements in colour and texture. A very new application is in the fabrication of the heat shields of spacecraft used to protect the occupants on their re-entry through the earth's atmosphere.

Nature of asbestos

The three main kinds of asbestos, chrysotile, crocidolite and amosite, usually occur as compact veins or bands of fibre sandwiched transversely between blocks or layers of finegrained rock which itself has no fibrous character at all, and yet is often virtually identical in chemical composition to the fibre it contains (fig. 6). Herein lies one of the great enigmas of asbestos; what causes it to be fibrous? The answer probably lies in a combination of factors involving not only chemical composition and atomic structure, but also conditions such as pressures, tensions concentrations, impurities, temperatures and rates of growth pertaining when the mineral first formed.

6
Examining a model of the crystal structure of asbestos which is magnified 150 million times. In the foreground is a rock in which two layers of asbestos fibres may be clearly seen.
Photo: Walter Nurnberg, London.

It has for some time been assumed that the fibrous nature of asbestos resulted form its crystal structure containing a chain-like configuration of atoms, but while this may be an influencing factor, it does not seem to be either a sufficient or a necessary condition. All amphibole minerals, including crocidolite and amosite, do have a chain-like atomic structure, but many amphiboles (including riebeckite and cummingtonite which are close in chemical composition to crocidolite and amosite asbestos respectively) form in roughly equidimensional crystals rather than in fibres.

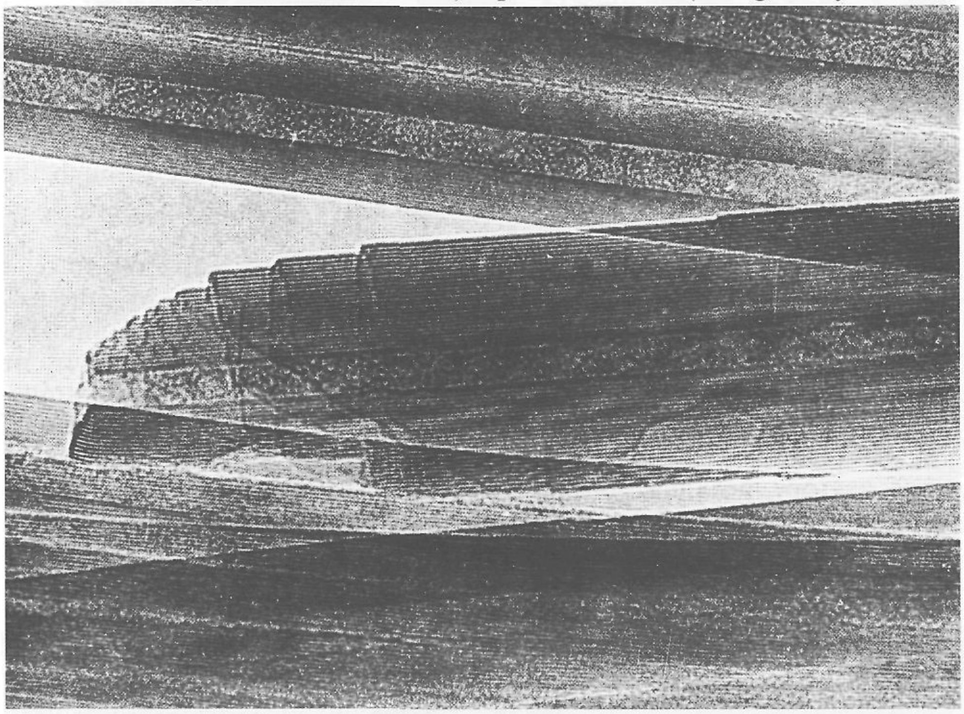
The atomic structure of chrysotile was once thought to be chain-like, but it is now known to be fundamentally of a layered character, a feature which in many other minerals (e. g. mica) leads to platy morphology. This paradox has been resolved via a number of different avenues of research, but none more direct that the recent work of K. Yada[11]. His electron micrographs of transverse and longitudinal views of fibres (fig.7) show them to be composed of sheets of atoms curled up like rolls of carpet. The lengths of these rolls are great compared with their diameters, a typical fibre being about ½″ long and one millionth of an inch across. This fineness, which applies also to amphibole fibrils (though they are not roll-like), explains why it is possible to strip off very fine threads of asbestos, each thread still containing many thousands of fibrils.

Chemically, the asbestos minerals are all hydrous silicates, of magnesium in the case of chrysotile, of iron and magnesium in the case of amosite, and of sodium and iron for crocidolite. The serpentine minerals (including chrysotile asbestos) have a composition near to $Mg_3Si_2O_5(OH)_4$, while the amphiboles have the general formula $X_{2-3}Y_5(Si,Al)_8O_{22}(OH)_2$ with X and Y representing different elements in different amphibole varieties. Crocidolite approximates to $Na_2Fe^{3+}{}_2Fe^{2+}{}_3Si_8O_{22}(OH)_2$, and amosite approximates to $Fe_5Mg_2Si_8O_{22}(OH)_2$. Of the less common asbestos minerals, anthophyllite is similar in composition to amosite, but has more Mg than Fe; tremolite has the formula $Ca_2Mg_5Si_8O_{22}(OH)_2$, and actinolite is like tremolite but contains significant Fe and Al.

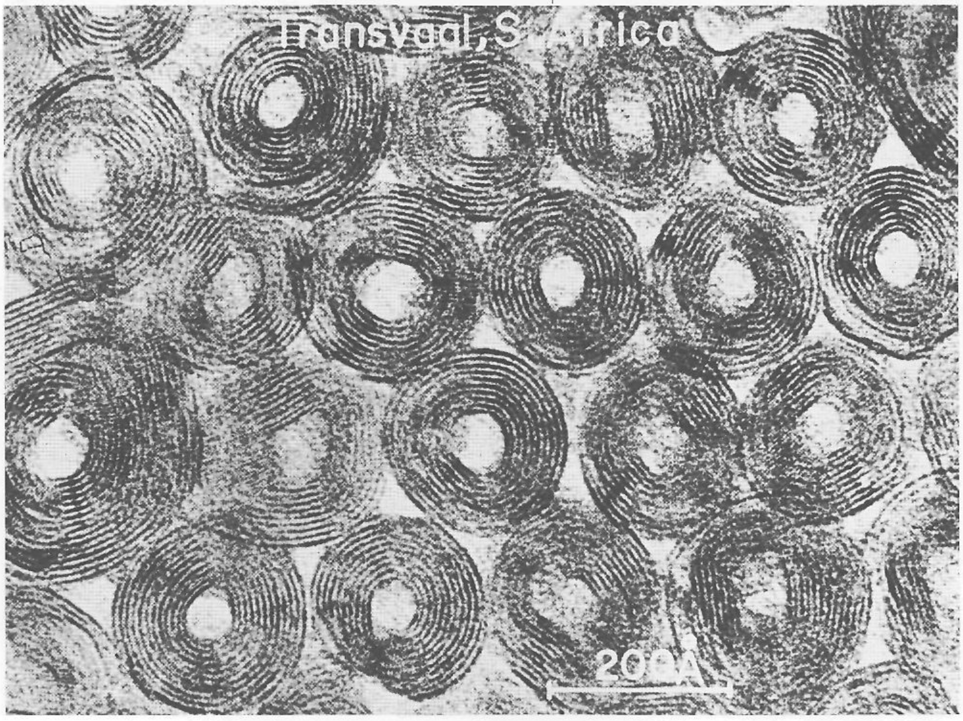
Properties

When crocidolite or amosite is heated above 200 °C, or chrysotile above 500 °C, their chemical composition starts to change, until at 700 °C or 750 °C they have lost their hydroxyl as water; these and other changes are accompanied by a reduction in tensile strength. Beyond this, further chemical changes take place yielding refractory silicates and oxides which melt only at temperatures above 1200 °C. At no temperature can asbestos be said to "burn". Articles made from asbestos will begin to lose strength when heated beyond a certain temperature, which may be higher than the temperature at which the corresponding fibre begins to decompose. The loss in strength may be gradual, and the shape of the product is generally retained until quite high temperatures. Another important property of asbestos is its very low thermal conductivity (perhaps due in part to the pore space between fibres). This, as much as its incombustibility, contributes to its usefulness in fire prevention. Asbestos is also low in electrical conductivity, so that it is useful for electrical insulation. Other highly desirable properties of asbestos are the tensile strength, elasticity, flexibility and length of its fibres (fig. 8).

Most silicates are highly resistant to attack by acids, and this is true of all asbestos except chrysotile which is attacked by relatively weak acids leaving a siliceous residue. This clearly militates against the use of chryso-



7
Dr. K. Yada's electron micrographs showing transverse and longitudinal sections of chrysotile "tubes".



tile in certain chemical plant applications, but chrysotile makes up for this limitation by having the best combination of tensile strength and flexibility. Amosite is relatively weak and brittle, and therefore is not good for spinning and weaving purposes, but it is ideal for use in thermal insulation materials made from asbestos-cement mixtures. All varieties resist attack by alkalis.

8
Table:
Comparison of properties of varieties of asbestos.

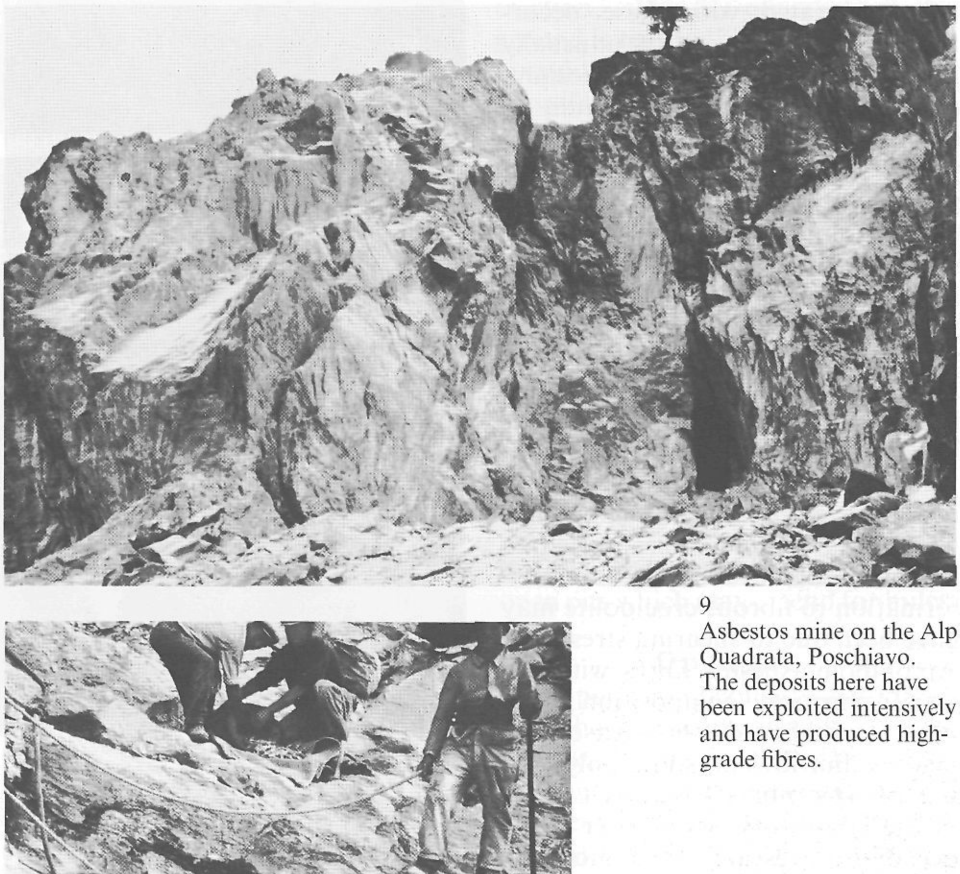
	Chrysotile	Amosite	Crocidolite
Tensile strength (1000 psi)	150–500	200–350	300–550
Flexibility	very good	poor	good
Acid resistance	poor	good	good
Lustre	silky	vitreous-pearly	silky-dull
Texture	soft	coarse	harsh
Density (gm/cm³)	2.5	3.2	3.5
Hardness (mohs)	3–4	5.5–6	5.5–6
Heat resistance	good	good	good (melts earlier)

Occurrences and origins

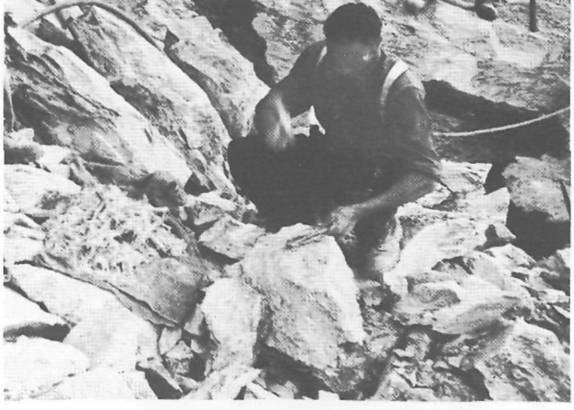
The principal occurrences of chrysotile are in the Province of Quebec, British Columbia and the Yukon Territory, Canada; the Bazhenov district of the Urals; Eastern Siberia; Rhodesia and Swaziland. The main source of blue asbestos is Cape Province, South Africa, and of amosite, the Transvaal. Among the localities of less extensive asbestos deposits are Cyprus (mainly chrysotile), Italy (mainly tremolite) and Finland. In Australia there is a large crocidolite deposit at Wittenoom Gorge, and chrysotile occurs also here and elsewhere in Australia and New Zealand. Bolivia is a source of crocidolite, and amphibole and chrysotile asbestos occur elsewhere in South America. Among the scattered occurrences in the U.S.A. are those of chrysotile in Arizona and Vermont and crocidolite in California.

It is estimated that the known deposits of asbestos are sufficient to meet industry's needs for about 30 years hence. However, new deposits will no doubt be discovered, and through changes in mining techniques and in transportation methods asbestos may be extracted in what are at present uneconomic situations, so that it will probably be much longer before the world's supplies are anywhere near exhausted.

The serpentinite rocks in which veins of chrysotile fibre occur have usually resulted from hydrothermal action on ultrabasic rocks which were either peridotite, containing the minerals pyroxene and olivine, or dunite consisting mainly of olivine. The iron content of the above rocks seems to emerge as magnetite and other iron oxides, leaving the serpentine relatively iron free. Chrysotile fibre veins have probably been formed at a later stage in the history of the rock, but there are various mechanisms by which the fibres may have developed. They may have grown from fresh solutions circulating in existing fissures, or may, with or without the aid of water or solutions, have recrystal-



9
Asbestos mine on the Alp Quadrata, Poschiavo. The deposits here have been exploited intensively and have produced high-grade fibres.



10
Mining on the Alp Quadrata: The fibres are separated from the adherent rock by hand (right); the crude asbestos thus obtained can be seen spread out on the bag.
Photos 9 and 10: with the kind permission of the Swiss Collecting Office for Geological Documents, Berne.

lised from the wall rock on either side or from one side of the fissure. Another possibility is that the fibre grows in a widening fissure and may help to push the walls apart.
An alternative rock from which serpentine and hence chrysotile is derived, is an impure siliceous dolomite, as found in the Transvaal.
The two important amphibole asbestos minerals, crocidolite and amosite, occur in "banded ironstone" formations which contain ferruginous slates, quartzites and jaspers. Probably associated with these occurrences is the presence of unusually high concentrations of magnesium, and for the crocidolite, sodium as compared with the rock material, which is normally rather poor in these elements. It is generally thought that dolomite is the source of the magnesium, and that crocidolite rather than amosite formed along particularly sodium-rich bedding planes of the ironstone formations. Blue amphibole probably first occurred as the crystalline mineral riebeckite, with little or no addition of material and under conditions of moderate temperatures and pressures when the ironstones were buried to moderate depth. The later transformation to fibrous crocidolite may have been due to shearing stress.
Amphibole asbestos fibres with unusual chemical composition have been synthesised in reasonable lengths, but for chrysotile only submicroscopic fibres have been made in the laboratory. Even after many decades of research, the mode of growth of natural asbestos fibres remains largely a matter of conjecture.

11
Amiantus, an amphibole asbestos from the Steintal (Canton Uri) of the type which is frequently found in alpine fissures. Due to the shortness of its fibres, it is only of interest as a collector's item.

12
Amphibole asbestos from the Findelen Glacier near Zermatt.
Photos 11 and 12: Central Advertising. With the kind permission of the Natural History Museum, Basle.

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Mining and milling

by B. Lincoln

The rate of production of asbestos has increased progressively in the last two decades. Although there have been periods of over-supply, there seems to be no likelihood of any slackening of world demand in the immediate future. In 1969 or 1970, world production could exceed four million tons. Chrysotile asbestos accounts for more than 90% of world production. The remainder is crocidolite (blue asbestos) and amosite, along with much smaller tonnages of anthophyllite and tremolite.

Reserves

Current world production statistics may prompt questions regarding the foreseeable life of existing asbestos deposits, many of which are now being worked at rates not originally envisaged. The answer is not easy to formulate in terms which are universally applicable. The factors to be considered include the geographical location of the orebody, the grade and quantity of the apparent ore reserves, the costs of developing and mining the ore and of recovering the fibre from it, the availability of skilled labour, the proximity of suitable transport routes, and access to sufficiently large and properly situated markets.

Unlike metals or petroleum, asbestos has to be taken very much as nature has left it, insofar as the fibre length distribution in the orebody cannot be improved. Metals recovered as small particles can be recast into ingots and oil can be subjected to distillation, cracking and catalytic reforming. But asbestos has a preordained particle size distribution.

Mines yielding predominantly short, low priced fibres must have large markets nearby if transportation costs are not to be prohibitive; mines containing a large proportion of long, higher priced fibre must rely on exports to many countries since the amount of long fibre which can be used in any one country is limited by its cost and the specialised nature of its applications. Between these extremes, there is a very large tonnage of medium priced asbestos. This has many uses and is sufficiently in demand to permit transport to all parts of the world, although the respective geographical locations of producer and customer still have some influence on the economic usage.

Any estimate of workable reserves therefore depends to some extent on present availability from the more conveniently located deposits. The known sources of supply appear likely to be adequate for the next thirty to fifty years, i. e. effectively into the 21st century, for which point of time it is impossible to forecast technical needs exactly. In any event, active exploration is still in progress, with new deposits being located and evaluated to ensure continuity of supply.

Country	Tonnage (1000s short tons)		
U.S.S.R.	1,500*		
Canada	1,497		
Southern Africa	450**	Chrysotile Crocidolite Amosite	200 150 110
U.S.A.	121		
Italy	125*		
Cyprus	19		
Finland	12	(anthophyllite)	
	3,724		

* Estimated
** South Africa, Swaziland, Rhodesia (estimated) Mozambique

13
Table:
Major World producers of asbestos – 1968.

Mining methods

The method adopted for extracting asbestos ore depends on the shape and location of the deposit, i. e. whether it is a compact block, or thin and extended, and whether near the surface or at depth. It has been customary to begin with surface extraction, either by quarrying if the ground is reasonably flat, or by driving adits (horizontal or inclined tunnels) if the terrain is hilly. There is no hard and fast rule, however, and local conditions usually dictate the final choice.

Modern tendencies, given the advantage of an extensive prior survey of the orebody by drilling, are to adopt the method which is likely to yield the best return over a fairly long initial phase of say 15 to 20 years, and to keep in mind the possibility of a change in technique around the end of that period. Some deposits, for example in Canada and the Urals, are so extensive as to justify almost indefinite extraction in open pits which may extend for miles.

Open pit

Open pit mining consists of forming "benches" or steps, usually between 10 and 30 metres high, on which drilling machines, loading shovels and heavy dumper trucks can operate (fig.15). The rock is broken by drilling near-vertically and horizontally, then inserting explosive charges which are

14
Aerial photograph of the
Normandie Mine of the
Asbestos Corporation Ltd.,
Thetford Mines, Quebec.

15
Open pit operation.
Photos 14 and 15:
Becker and Haag, Hamburg.

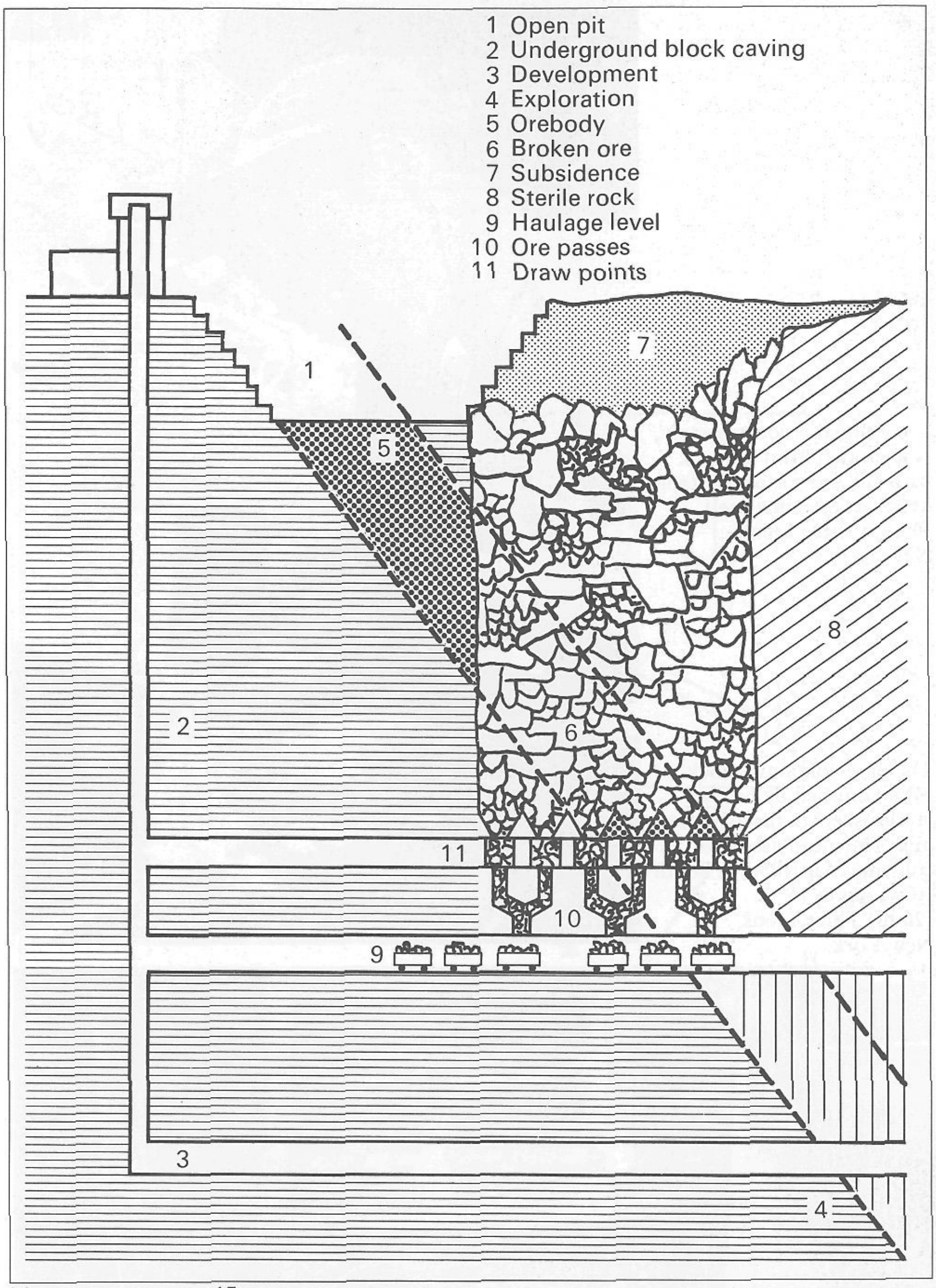
arranged to avoid excessive shattering of the ore and consequent damage to the fibre. The broken rock must be raised to ground level from the floor of the pit. In the first years of operation at least, this can be done by trucks running on spiral benches. With deeper pits, the tendency is to truck the ore across the bottom of the pit to the loading point of an inclined hoist.

Open pit operation becomes progressively uneconomic as the depth and hence the relative amount of peripheral overburden increases (fig. 16). In most deposits this phase of activity is superseded in due course by underground working. In northern latitudes open pits are exposed to severe weather, but this disadvantage has now been overcome even in the extreme winter conditions around 60°N and at altitudes up to 2000 metres in North West Canada and the Urals. The chief advantages of the open pit are low first costs plus the ability to select ore visually, and thereby to maintain constant characteristics in the feed to the fibre recovery plant.

Underground

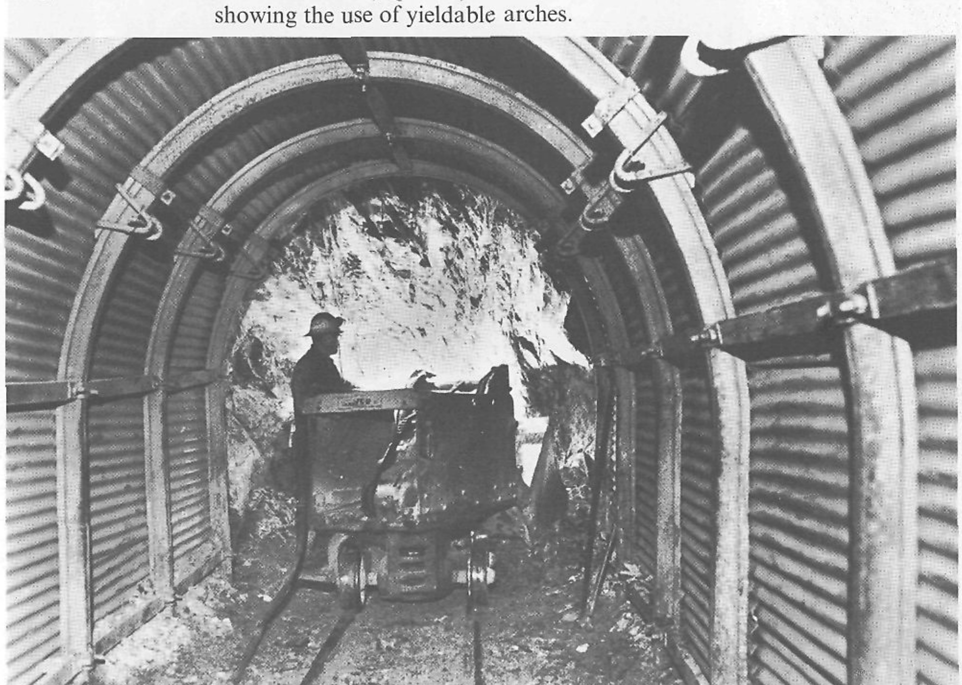
Choice of an underground mining method is influenced by the nature of the orebody. If it is massive, wide, and of suitably hard rock, one of the various types of caving will usually be employed. These rely on the tendency of a mass of rock, if undermined and containing incipient fractures such as veins of asbestos, to disintegrate and collapse under its own weight plus that of any overburden. The broken rock gravitates into a complex of specially prepared drawpoints, from which it falls through ore-passes to the haulage level (fig. 17). The drawpoint and loading levels are in steel and concrete. They look like installations in a well-organised factory and they have contributed to the high standards of safety which are now commonplace. The cost of developing the underground systems, with its associated haulage ways and hoisting shaft, is necessarily high. Still, caving permits large quantities of ore to be broken and handled at relatively low operating cost, since much less temporary roof support is required in the working zones than was needed in older methods.

In flatter, tabular orebodies retreat caving may be used. The blasting starts at the upper surface, or hanging wall, of the orebody and retreats progressively towards the lower surface, or footwall. Alternatively, the operation may retreat from one

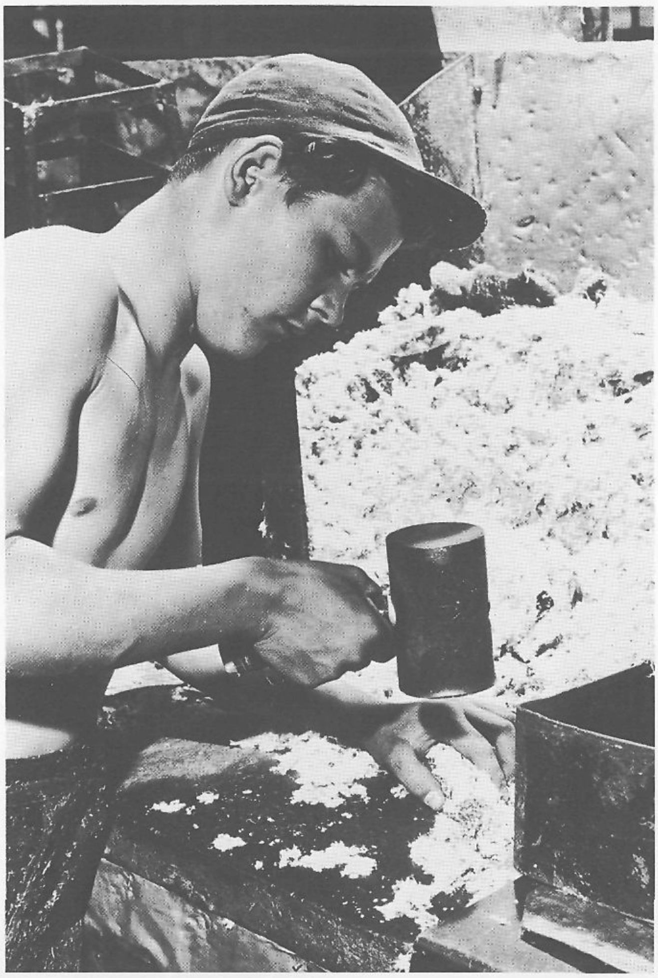


16
Stages in the life of an asbestos mine.

17
An underground gallery at Bell Asbestos Mines Ltd., Thetford Mines, Quebec, showing the use of yieldable arches.

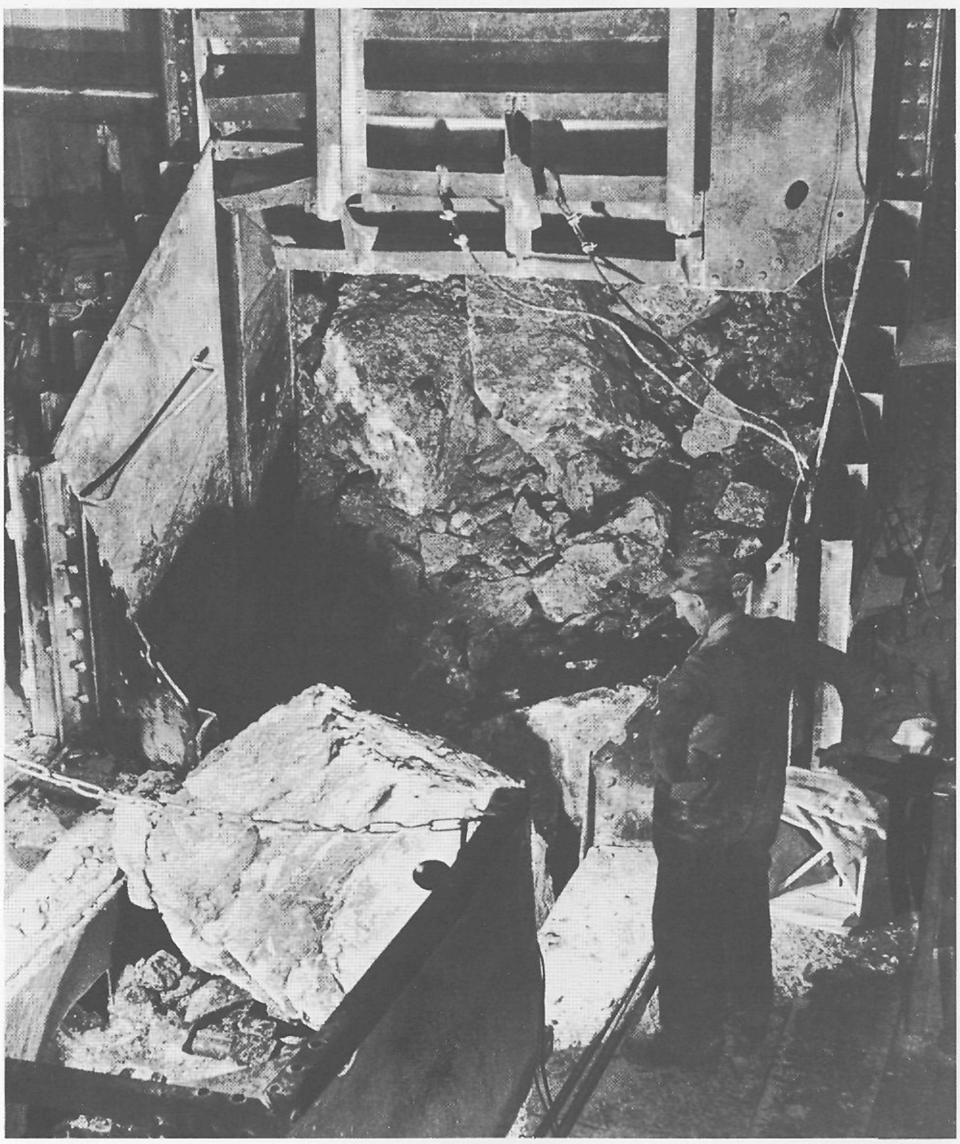


flank of the orebody to the other. These several variations on the caving principle have displaced the more traditional hand methods of stope and long wall mining, and they seem likely to predominate for many years.



18
Long-fibred crude asbestos is separated from the rock by hand and sorted by staple length at the mine itself.
Photo: Three Lions, New York.

19
The fibre-containing rock is first crushed by heavy jaw crushers in the asbestos mill. The mean asbestos *content is 4 to 10%, in South* Africa up to 15%.
Photo: Three Lions, New York.



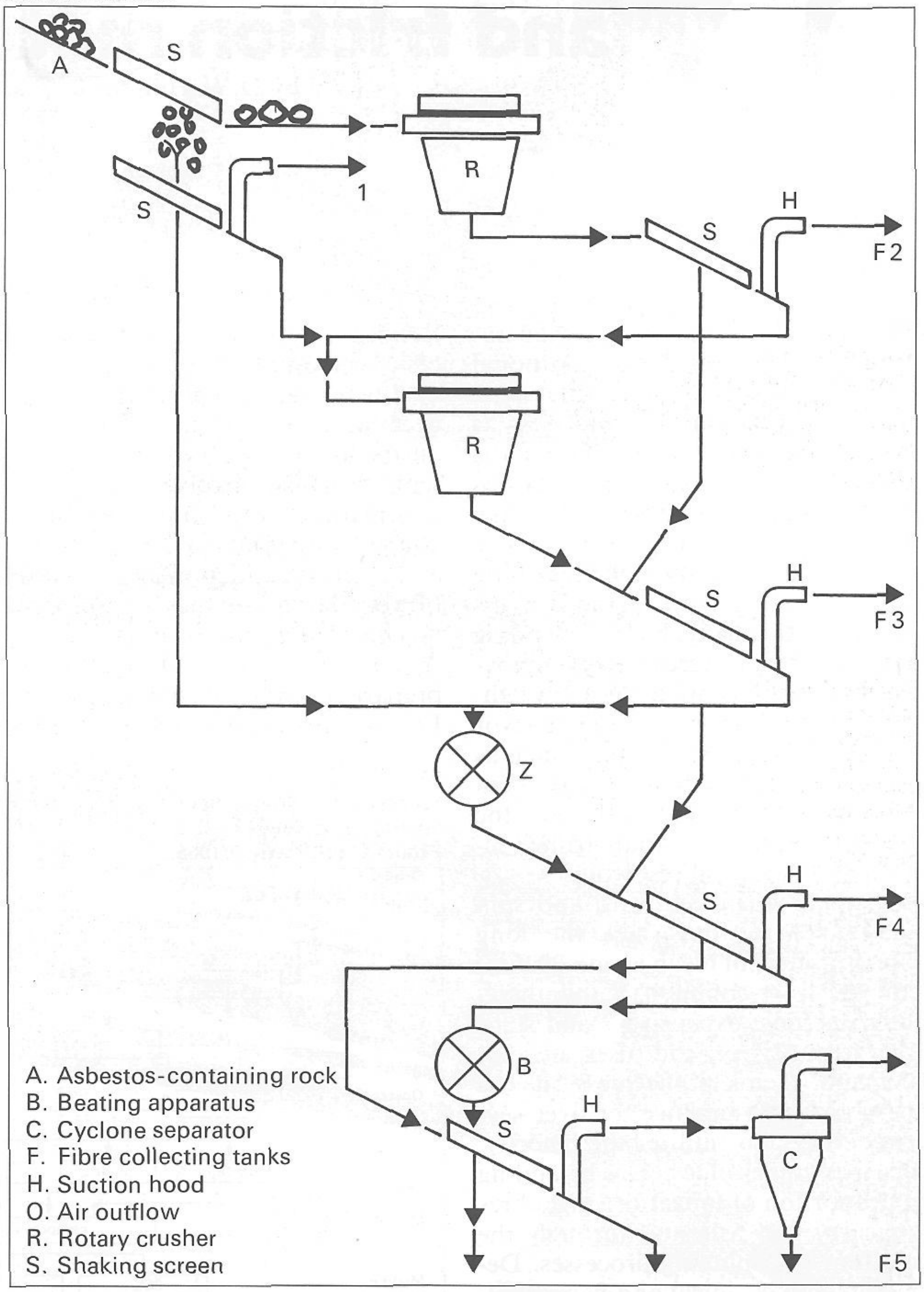
Milling

Ore from an open pit or underground mine often contains 90% or more of rock and less than 10% asbestos. Extraction of the wider veins, containing the longer asbestos fibres, presents no difficulty. It has long been done by "hand cobbing", i. e. cleaving away the rock at each side of the vein and dislodging any residual rock fragments by gentle hammering (fig. 18). The clean, crude fibre so produced is scarce and valuable, realising up to £ 500/$ 1200 per ton. The bulk of the millfeed ore consists of rock fragments ranging from one metre or more across to the finest powder. It has to be crushed and processed in such a way as to remove as much free dust as possible and to preserve the length of the asbestos fibre.

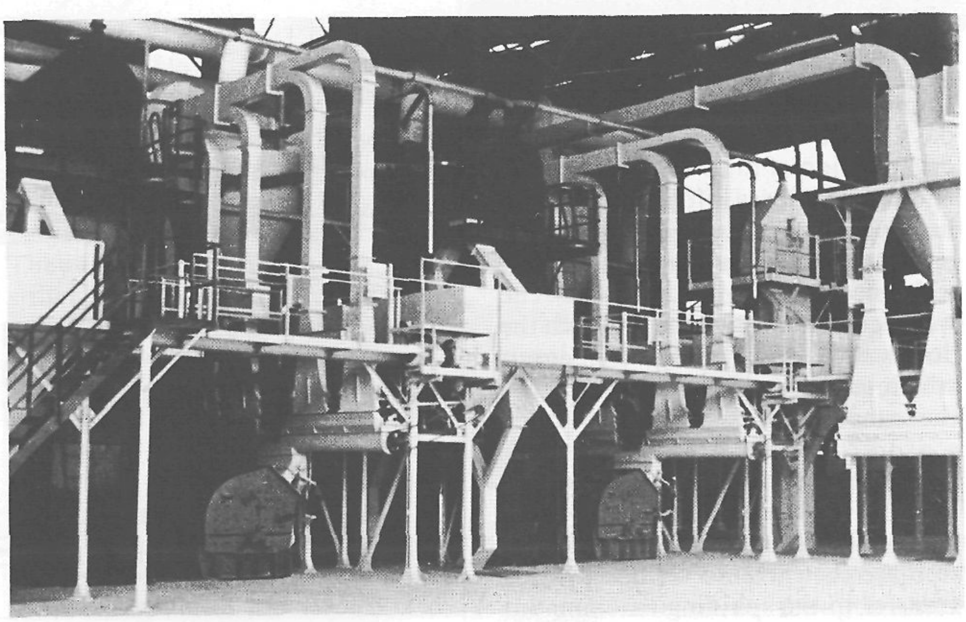
Asbestos mills employ a fundamental cycle of operations: crush, screen, and air lift of fibre. For all their complexity, most mills are multiple assemblages of this basic recovery cycle (fig. 20). The mill feed is first screened into two or more size ranges which are then processed accordingly. The asbestos concentrate lifted from each screening operation is regarded as having a mean length related to the size of the screen apertures, so that a rudimentary classification into length ranges is immediately established. The oversize rock from the screen is then recrushed and rescreened, whilst the undersize is passed further down line for finer screening and air lift before being crushed yet again. These processes may continue until all the rock is reduced to one-millimetre particles.

The fibre concentrates are given further sieving operations, and some may be blended together to arrive at the most desirable length for particular end-uses. Finally they are given a mechanical treatment to fiberise them to standard states of fluffiness. In some instances (e. g. long textile fibres) these processes may be followed by a dedusting operation which reduces to a minimum the content of short fibre and fine rock particles. In many modern asbestos mills the graded and cleaned fibres are pressure-packed into 100-lb rectangular impermeable sacks which have proved to be ideal for stacking, palletising and shipment.

20
Basic operations in recovering asbestos from ore.



At all stages of fibre recovery and final preparation, quality control methods are constantly applied. Length distribution is assessed by a multiple wet-sieving classifier, and fluffiness (termed "openness" in the industry) is measured either by an air permeability method or by wet elutriation. More specialised tests are often applied where the particular grade is destined for a specific end-use. Mineralogical characteristics are not susceptible to physical control, but they are monitored in instances where, for example, chemical purity is an essential requirement. Most of these controls have been introduced within the last fifteen years. They have resulted in the establishment of precise specifications with consequent benefits to the quality of the final products.



21
Fibre opening machine with suction apparatus.
Photo: Hazemag, Münster (D).

Asbestos textiles and friction materials

by D.W. Hills

Although there are special considerations in their handling, traditional asbestos textiles undergo the same basic manufacturing processes as many other textiles. In spite of the elaborate preparation of asbestos fibre at the mine (described in the preceding article) bag-to-bag variations in fibre quality still necessitate more blending, and in modern asbestos textile plants hopper blending lines are being increasingly employed. The blend components are weighed out in proportion on to a conveyor which feeds a mixing device, such as a picker. The blended fibres are then forwarded pneumatically to the cards, surplus material being returned to a central reservoir.

It is quite feasible to card and spin pure asbestos, but since the long fibres needed (of mean length 20 mm) are the least common – and therefore the most expensive – and since the majority of end uses do not demand chemical inertness, it has been common practice for over seventy years to utilise the shorter, cheaper grades of asbestos by adding a proportion of longer organic fibres to carry the asbestos through the carding and spinning processes. Depending on chemical and flammability requirements, the proportion of organic fibres added varies between 5% and 25%.

Carding follows blending and is the preparation of textile slivers for the spinning operation. From the earliest days of the asbestos industry, the organisation of randomly distributed and tangled fibres into a tenuous web has been best performed by the roller and clearer carding machine of the reclaimed waste fibre industry. The web is continuously removed from the doffer and fed to the tape condenser, which accepts a fullwidth web from the card doffer and splits it by a scissors action between alternate tapes that subsequently carry the strips of web to a stack of rubbing aprons. The consolidated strips of web are then wound on bobbins for transfer to the spinning machine.

Because carding is a dry, dusty process, enclosure and extraction of dust-laden air from machines has been practised in the asbestos industry for sixty years. The best current practice involves maximum automation of fibre handling, coupled with total machine enclosure and efficient extraction and filtration of very large volumes of air from machines and process areas.

A recently introduced method of preparing sliver for spinning is the Fortex[1] process developed from the ideas of Novak and others. As this is a wholly wet process up to the weaving stage, dust emission is eliminated and the structure of the dry yarns is such that rough handling of them produces only a fraction of the dust emitted by carded yarns. Fibre is blended in a process that is similar to the production of slurry for paper-making and involves mixing a charge of several bags of ex-mine fibre in water with chemical dispersing agents. The resultant dispersion of fibres in water is like thin, smooth

[1] Trade Mark of Turner Brothers Asbestos Co. Ltd.

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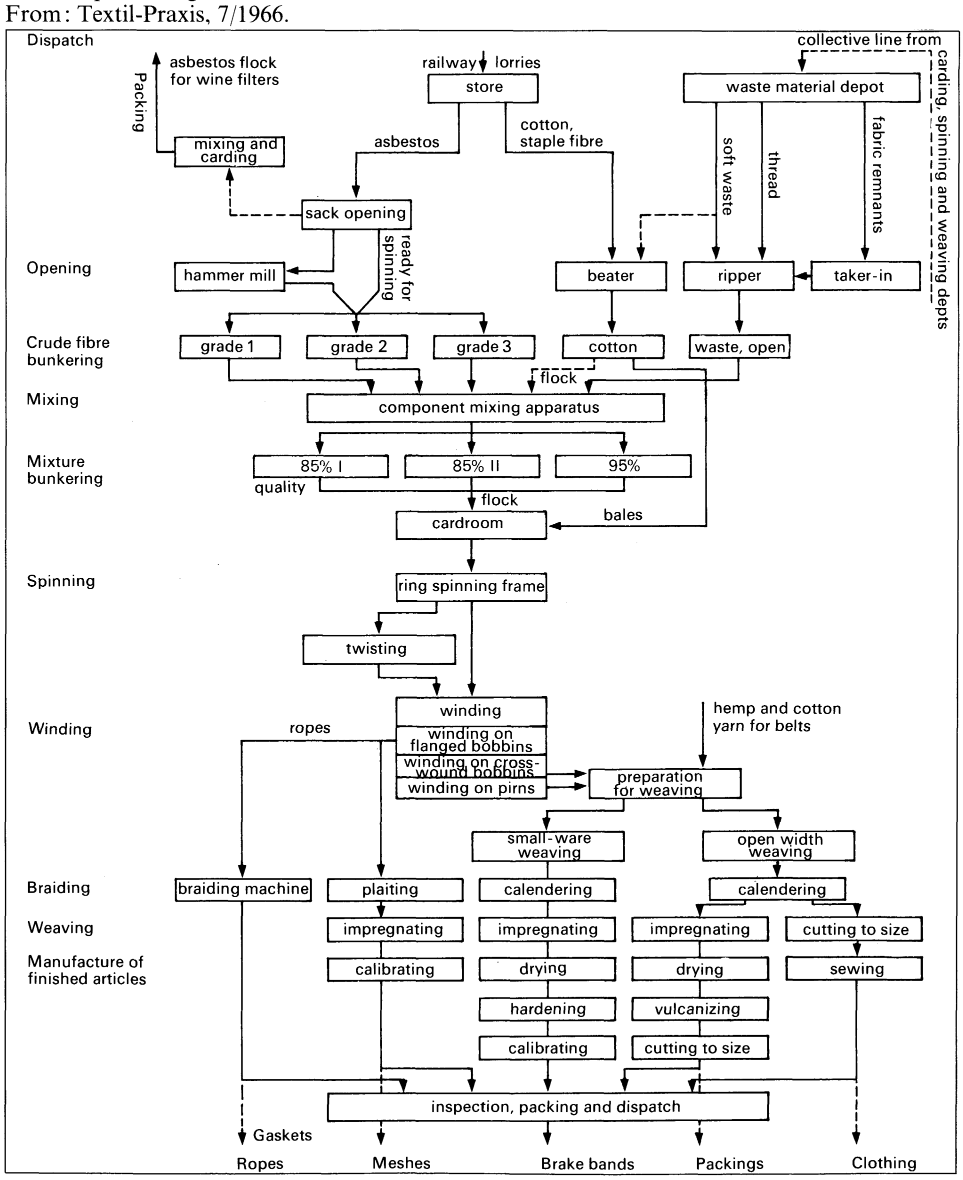
Schematic representation of asbestos processing.
From: Textil-Praxis, 7/1966.



23
Weaving asbestos cloth.

porridge in consistency and is extruded into a coagulant to form a tough, wet strand which is collected in suitable containers for presentation to the spinning machine.

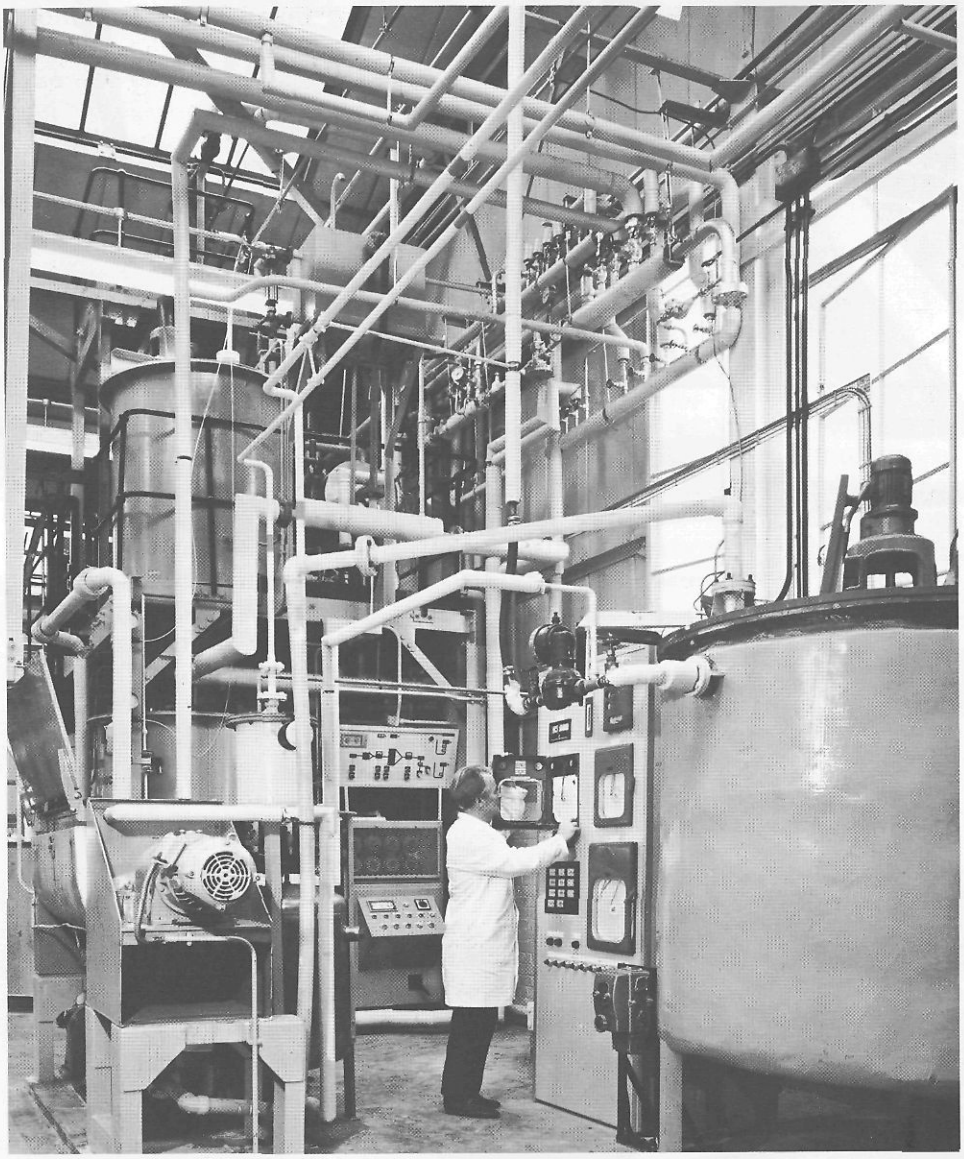
The Fortex process resembles certain other man-made filament processes in that considerable flexibility exists at the blending stage, when additives such as pigments, graphite, friction modifying powders, thermosetting stiffening agents and general purpose fillers may be incorporated in significant quantities.

Extraction of dispersing agents and solvents can be done by heating in an inert atmosphere in pressure dyeing vessels. Naturally, any yarn additives chosen must stand up to the extraction process.

Fortex yarns are characterised by a high degree of fibre alignment generated at the extrusion stage, with very finely divided fibre structures. They are therefore smoother and stiffer than carded asbestos yarns, which have a fairly random fibre structure with a wide fibre diameter distribution and hairy surface characteristics.

Spinning and doubling

The spinning operation imparts strength and regularity to the sliver by twisting it to form a yarn. Core strands of metal, cotton or synthetic fibres may be added to obtain certain special properties in the finished product. Flyer spinning frames are usually used. The sliver is unwound from bobbins in the case of carded sliver or withdrawn from containers in the case of Fortex sliver. It is then run between two feed rollers to the flyer and from there on to the bobbin. The relationship between the roller speed and that of the flyer produces the twist needed to strengthen the



yarn for further processing. The single-ply yarn thus created may then be "doubled" by being twisted together with one or more other yarns, its tensile strength thus being literally multiplied.

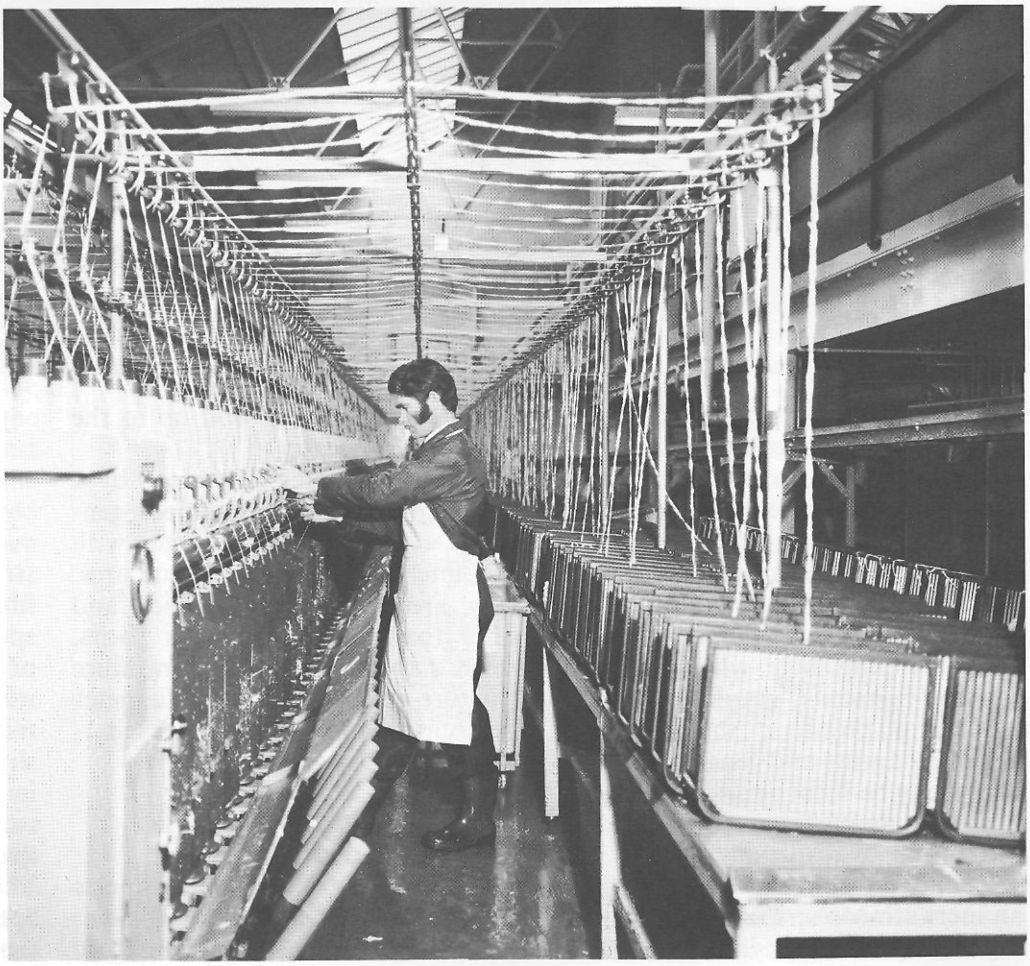
Weaving, braiding and plaiting

For the production of woven cloth, looms of simple conventional design are employed.

In the design of looms for asbestos weaving, the accent is on robustness and simplicity. Asbestos yarns are considerably less elastic and exhibit higher yarn-to-yarn friction than other textiles; consequently the forces on the loom slay and frame are much more severe than when similar fabrics are being woven from cotton or man-made fibre yarns.

For other purposes, such as the manufacture of tubings or packings,

24
Two sections of a plant for producing asbestos yarn by a revolutionary wet dispersion process. Left, the picture shows the network of pipes, tanks, valves and control consoles which has replaced the traditional carding enginges. Below, the wet strand is fed from tanks on to the spinning machine.



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The wet-spun roving is fed on to the spinning machine from tanks (right) as opposed to the conventional bobbins.

braiding or plaiting of the yarn is necessary instead of weaving. This is probably the oldest branch of the mechanised asbestos industry. Bobbin carriers are impelled along interlacing tracks by forked impeller wheels rotating below the tracks. The basic plaited product is a hollow tube. Solid articles are built by the plaiting of successive layers over a core of stuffer yarns, this process involving machines with ever-increasing numbers of bobbin carriers as the diameter is built up.

Other track patterns have been evolved which enable rectangular and flat articles to be plaited – an interesting one being a rectangular plait developed in 1930 for the simultaneous fabrication and impregnation of brake linings. Square articles are often made by adding stuffer yarns at the "corners" but this construction suffers from the fact that it may disintegrate once the outer layers have been worn through; a special track pattern was developed by Crossley some years ago which enabled yarns to be interlaced in depth, with the result that packings made to this construction enjoy a much longer working life. Many square plaited products are finished by being passed through sets of calender rollers to define their size.

Seals, gaskets, packings and jointings

After deposits of the mineral fibre asbestos were first mined commercially in the late 1870s, packings based on asbestos were tried out in steam engines and proved so great an improvement that they have been employed ever since to meet diverse sealing and packing requirements in the engineering field.

The function of a gland packing is essentially to prevent uncontrolled loss of the contained liquid or gas, or alternatively, to exclude air which might destroy a vacuum. In this context, the packing creates a seal between components where relative movement takes place as, for example in rotary and reciprocating pumps, air compressors and numerous types of control valves. Packings for applications of this sort contain a lubricant suitable for the conditions under which they operate, and may be termed dynamic seals.

Asbestos plaited packing is used as a form of static seal, and is found on the doors of autoclaves and ovens. Although this type of application does not normally require a lubricated packing, surface treatment with a high temperature lubricant such as flake graphite aids easy breaking of the seal when necessary.

Whilst they are not textile-based, gaskets and jointings may well be considered at this stage. These materials serve a wide range of applications and are manufactured by blending asbestos fibre with heat-resisting rubber mixtures and vulcanizing the compound under pressure. Their degree of resistance to high pressures and temperatures may be evaluated from the fact that one product of this type is incorporated in valve testing equipment operating on superheated steam at 140 kg/cm^2 (2,000 p.s.i.) and 538 °C (1,000 °F) in pipe flanges of 50 mm bore. Different grades of jointing are produced for application where exceptional resistance is required to acids, solvents, oils, gases, high octane fuels and other aggressive chemicals.

26
Assembling asbestos-based automotive gaskets.

Cylinder head and exhaust manifold gaskets, in addition to almost every other gasket on an internal combustion engine, are asbestos-based in one form or another. Traditionally, cylinder head gaskets have been manufactured from asbestos millboard and copper, though there is now a tendency to use a compressed asbestos fibre jointing with wire inserts.

Asbestos textiles for electrical applications

The unique properties of asbestos have led to its use on a wide scale in electrical insulation. Asbestos cannot burn and will not splinter or disintegrate when in contact with a flame. It withstands high temperatures more effectively than any of the resins with which it is normally incorporated, and it remains unaffected by a combination of moisture and heat. Asbestos fibres will help to restrict the thermal expansion of materials with which they are combined, while asbestos-based products enjoy considerable resistance to impact and abrasion. Furthermore, when the fibres have been suitably processed, they become flexible enough to conform to sharp radii and are therefore ideal for insulation in electrical cables and armature coils.

Fire barriers

Fire barriers in various forms represent perhaps one of the earliest ways in which manufactured asbestos was employed in the service of man. Today, asbestos cloth is used for fire blankets in schools, hospitals and public buildings and for safety curtains in cinemas, theatres, factories, warehouses and aircraft hangars. Curtains may also serve as firebreaks in roof spaces of all kinds and as screening in forges and welding booths where there is a high incidence of sparks and radiated heat.

Fire-protective clothing

Conventional woven asbestos cloth has long played its part in providing protection for workers in industry. Many different items of clothing are available for this purpose.

Aluminized asbestos fire-protective clothing was introduced to the public at a motor race in March, 1966. The material represented an important advance in its field, being more heat-resistant than the non-aluminized cloth and at the same time lighter in weight and therefore more comfortable to wear.

27
Coat, hood and leggings made from aluminised asbestos cloth.

Since the particular virtue of this material lies in its high heat reflection, the basic cloth has been adopted for industrial use as a finishing wrap on hot lagging installations, where heavy radiation losses may consequently be reduced to negligible proportions and convected heat loss dissipated harmlessly.

Friction materials

One of the most common and most significant applications of asbestos is at the same time, one of the least visible – the automotive brake lining.

It was in 1908 that Herbert Frood, the British pioneer in this field, first experimented with asbestos for this application. These tests proved successful and demonstrated that a combination of pure woven asbestos (spun on brass wire to increase its strength) and a specially developed bonding agent produced a friction material with the requisite high friction properties. By the outbreak of the First World War, woven asbestos brake linings were in common use not only on standard cars but also on heavy commercial vehicles, on many types of mechanised military transport and in colliery equipment.

In 1921 Frood developed the first example of a moulded brake block, which was a vulcanized combination of ground-up waste bonded asbestos and a rubber-type binder. Its initial application was on motor cycles, moulded linings for the brakes of cars and commercial vehicles following a year or so later. It was not, however, until after the Second World War that moulded brake linings became widely accepted for everyday use, and today they are fitted as standard equipment on most new vehicles. They are manufactured by mixing asbestos fibres and other ingredients with a resin and polymerizing the resultant compound under pressure and at high temperature.

The same principles apply to the manufacture of disc brake pads, which were originally used in aircraft landing wheel brakes in 1944. Disc brakes were extended to the motor racing world in the post-war period and have over recent years become standard equipment even for many cars in the "popular" range.

Brake linings provide by no means the sole automotive outlet for asbestos-based friction products. Another important application is the clutch facing, and in many ways these two pieces of equipment have followed parallel courses. The introduction of impregnated cotton, in place of leather, for the original cone clutches of motor vehicles took place in about 1905. Later, the switch to asbestos was made and in due course the dry plate clutch superseded the cone design. Today, clutch facings based on wire covered with asbestos yarn continue to be widely employed in spite of progress on the moulded side.

Two rapidly increasing non-automotive applications for asbestos friction materials should be mentioned. First, asbestos brake blocks have made inroads into the important railway market, a field in which continued expansion may be anticipated, particularly as the railways introduce disc braking to their locomatives and rolling stock. Secondly, there is the development of the anti-slip stairtread, which is now used as a safety precaution in public buildings of every description and has been successfully adapted for the steps and platforms of public transport vehicles and coaches.

28
Drilling the rivet holes in a brake lining in one operation.

29
Asbestos-based friction material is incorporated into anti-slip stairtreads.

Asbestos-based building and civil engineering products

by J. K. Shepherd

Asbestos cement building materials

When Ludwig Hatscheck, an Austrian, discovered towards the end of the 19th century a process for reinforcing cement with asbestos fibres, he laid the foundation of what was to become a vast building materials industry. Asbestos-cement today represents the largest field of applications for the world's production of asbestos fibres.

The first stage in the manufacture of asbestos-cement is to blend selected asbestos fibres, which are then conveyed to a mixing vessel with cement and water, where a slurry is formed; the mixture is fed to the making machine, an essential part of which is a revolving circular wire sieve through which water from the slurry drains away leaving a thin film or lamina of asbestos impregnated cement on the wire mesh; this film is transferred to an endless felt and carried thereon to a revolving bowl on which successive layers of the film are superimposed until the required thickness of the finished sheet is built up. The material is subsequently cut from the bowl to become a flat pliable sheet which is sufficiently tough to be handled freely but which can nonetheless be moulded and shaped (figs. 30–33).

Basically, the above operations are present in the manufacture of nearly all asbestos-cement products; the material is initially a flat sheet of uniform thickness which may ultimately become an entirely new shape. Asbestos-cement pipes are however made differently as described later.

The most desirable properties of asbestos-cement are its durability and non-combustibility. In 1960, the Technical Committee responsible for compiling the British Standard Code of Practice dealing with asbestos-cement roof coverings reported that: "Asbestos-cement may be regarded as having a life of at least forty years except in unfavourable conditions, but the durability of the fixing accessories should be taken into account".

The late Dr. Jones of the Building Research Station who was responsible for the production of Technical Paper No. 29, "Weathering Tests on Asbestos-Cement Roofing Materials", whilst concluding in 1946 that atmospheric carbonation of the surface on an asbestos-cement sheet resulted in a reduction of the impact resistance of the material, added that such chemical action also tended to increase its transverse strength.

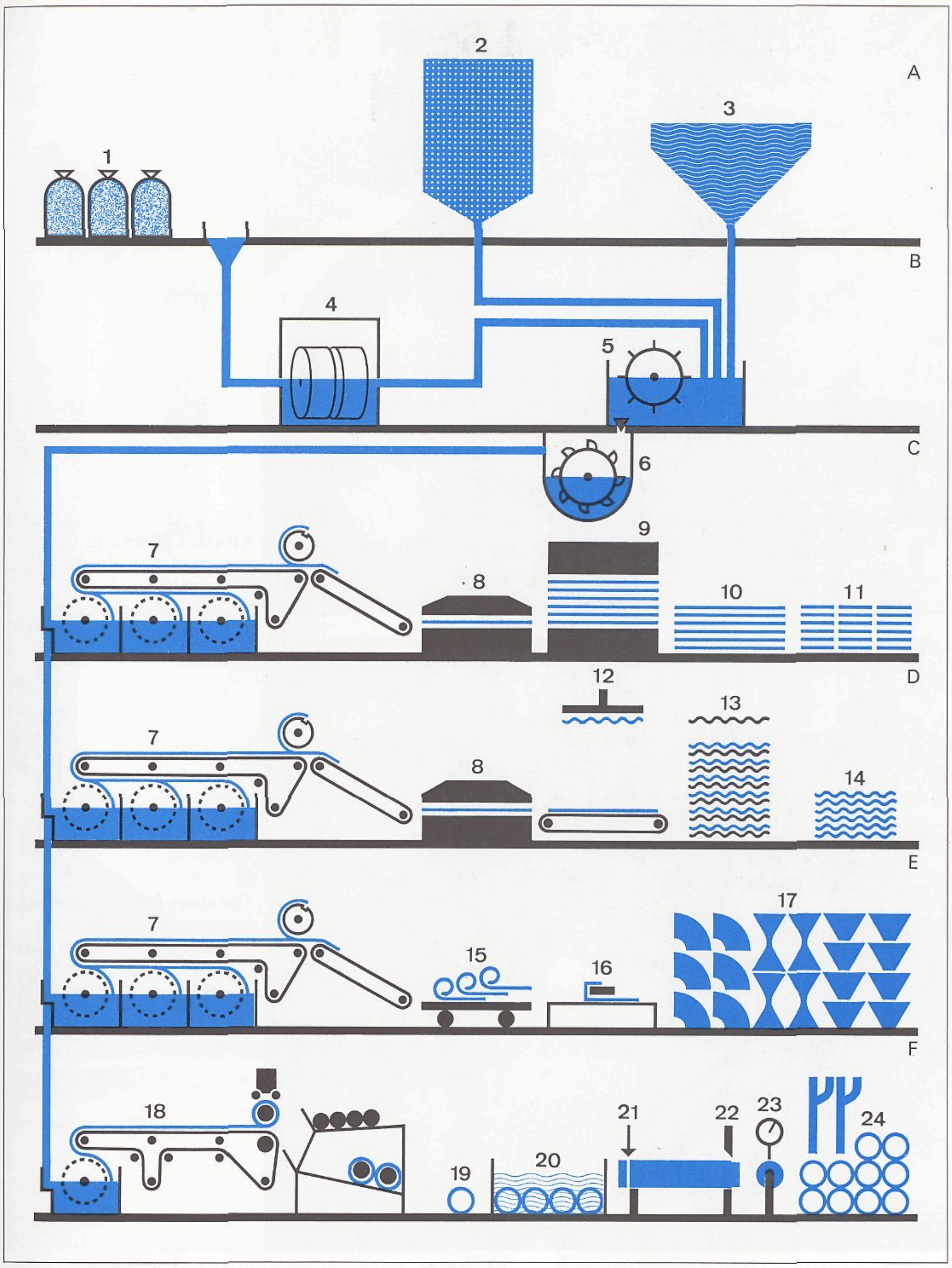
These comments on the durability of asbestos-cement have been confirmed by the experience of manufacturers in carrying out comparisons between the strength of new sheeting and that of sheeting exposed for a number of years to polluted atmospheric conditions. In one test, the failing load of corrugated sheets which had been exposed for a period of 17 years in the highly industrialised environment of Widnes, Lancashire, was demonstrated to be approximately 25% higher than that of unexposed sheets.

It should be emphasised that the strength of asbestos-cement in compression is far higher than in tension; as a result several types of corrugated sheeting have been designed to exploit this property and they are extensively employed for the roofing and vertical cladding of factories, industrial buildings and domestic garages.

Flat building sheet is also made in many different types, the density of each varying according to its ultimate function; ordinary or high density sheets may be used for external cladding applications and special low density panels containing a larger proportion of asbestos fibres are designed for use as infill panels for curtain wall systems, for fire-resisting partitions, for ducting and for doors. Asbestos insulation boards of a lower density are also widely used for partitions and ceilings in schools, hospitals, office blocks and multi-rise housing to give structural fire protection.

For fire protection purposes asbestos-cement sheeting has successfully passed the appropriate tests and may be correctly classified as non-combustible (Britsh Standard 476:53 "Fire Tests on Building Materials and Structures"). Indeed, the slow rate of heat conduction through asbestos-cement materials helps to retard the spread of fire through structures of which they are a part.

The serious hazard of fire at sea and the important role of asbestos in this context should also be noted. Many of the shipping disasters of the past would have been prevented had there been planned fire protection in the vessels involved. The breakthrough came nearly 40 years ago, when experiments were undertaken by Turners Asbestos Cement Co. Ltd. with a composite asbestos panel designed

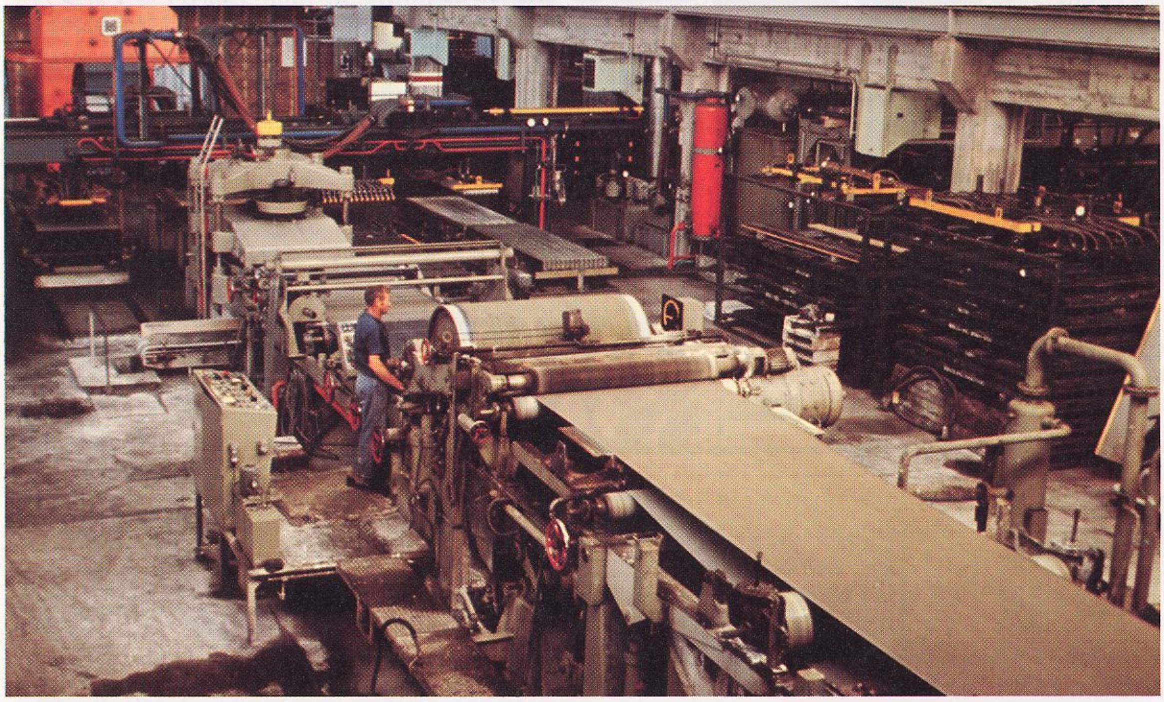


30
Schematic representation of the manufacture of asbestos-cement products.

A Raw materials
B Preparation for the manufacture of
C Flat sheets
D Corrugated sheets
E Moulds
F Pipes

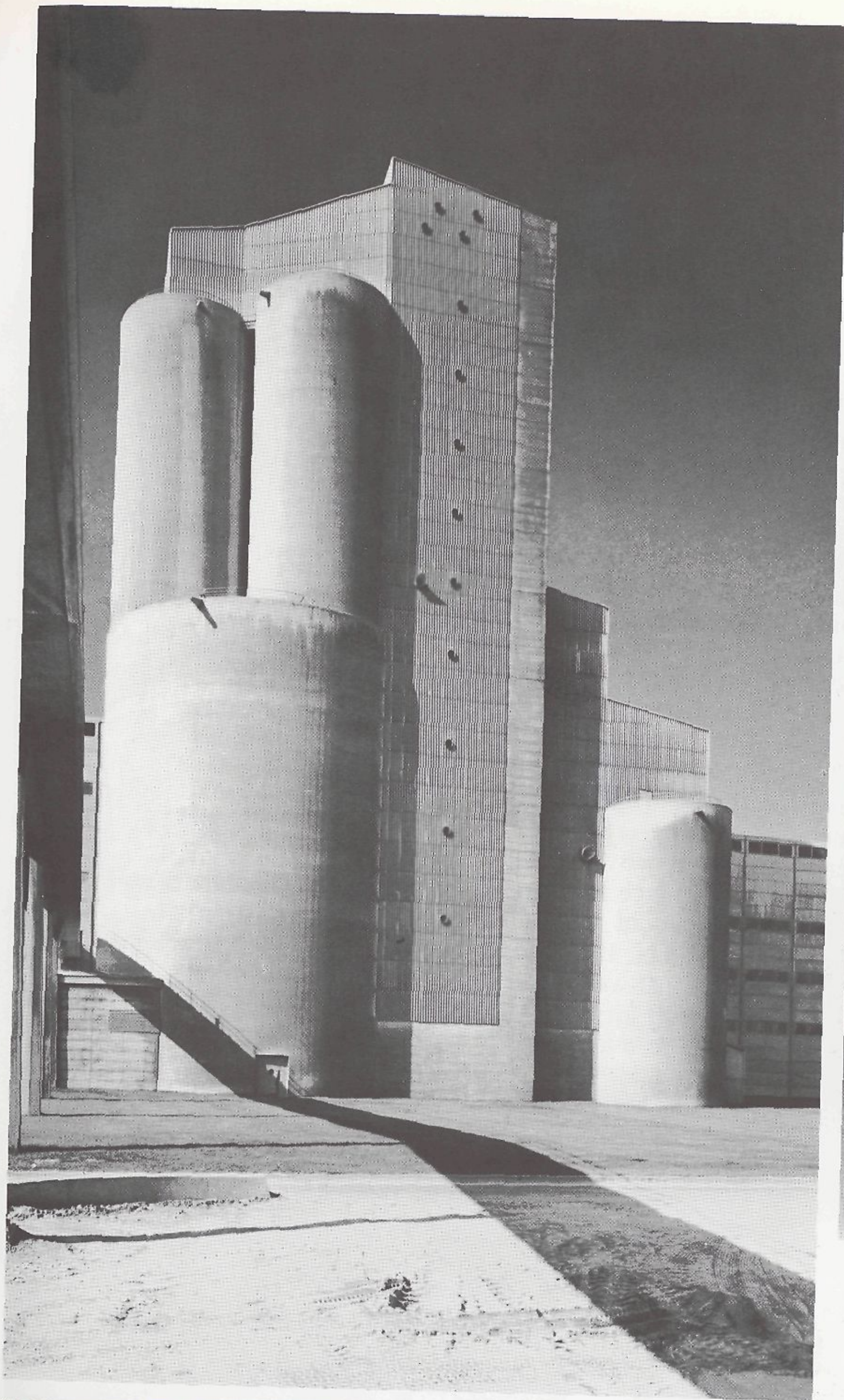
1 Crude asbestos from Canada and South Africa, delivered to the factory in bags
2 Portland cement pumped into the factory silos from railway containers
3 Saturated limewater for mixing asbestos fibres and cement
4 In the kollergang the asbestos fibres are finely opened
5 The asbestos fibres and cement are mixed with ample water in the beater to form a homogeneous slurry
6 From the stirring tank, where the asbestos cement slurry is kept in continuous motion, the mixture is fed into the filter boxes of the machines which produce sheets or pipes
7 Rollers form the asbestos cement web into sheets 3 to 20 mm thick
8 The wet flats are cut into the required shapes on the cutting table
9 The wet flats are pressed under high pressure to form roofing and facing components
10 The sheets are stored for curing
11 Tiles for roofing and facing, cut into the various shapes and sizes required, are stored ready for dispatch
12 Wet flats are formed into corrugated sheets
13 The corrugated sheets are deposited in oiled steel molds
14 Corrugated sheets for roofing and facing are stacked in the storeroom for air-curing
15 The still unhardened flats are brought to the molding shop
16 By using different dies, articles of all shapes and sizes are produced
17 Flower boxes, plant pots, ventilation shafts and all the other various articles molded from asbestos cement are air-cured prior to delivery
18 A felt conveyor deposits layer after layer of the thin asbestos cement web on the steel mandrel, until the wall of the pipe reaches the desired thickness
19 The steel core can be removed only a few hours after manufacture
20 Before being subjected to final processing, asbestos cement pipes are treated with water in large tanks
21 The asbestos cement pipe is cut to the required length
22 The ends of the pipes are calibrated to avoid unnecessary work when they are coupled up during laying
23 All pressure pipes are carefully tested at operating pressure before leaving the factory
24 The pipes are stored in the open for air-curing

31
Asbestos fibres and cement are mixed with abundant water in the beater to form a homogeneous slurry.



32
The sheet-forming machine transforms the asbestos-cement slurry into wet flats which can subsequently be moulded.

33
A mushroom head for use in reservoir construction is formed from freshly produced asbestos-cement sheets.



34
A cement factory in Göllheim (D) built from reinforced concrete and corrugated asbestos-cement sheets.
Photo: Rübartsch, Heidelberg-Leimen.

35
Measuring deflections of an asbestos-cement roofing structure during an accelerated weathering test.
Photo: Walter Nurnberg, London.

36
Coloured asbestos-cement roofing on the community centre in Wiesendangen (CH).

to contain any outbreak of fire on the "Queen Mary", then under construction. Full-scale fire tests on mock cabins showed that composite panels of this sort acted as effective barriers and many thousands of square feet of the material, known as asbestos ships board, were subsequently used in the construction of bulkheads and linings throughout the ship. Continued product research and development in this field led to the production of a non-combustible asbestos/silica board that met a wide performance specification.

Asbestos ships board materials were able to satisfy the international regulations enacted after the second world war in an attempt to control the dangers of fire in ships; the legislation introduced in 1948 under the International Convention for the Safety of Life at Sea specified non-combustible materials for the construction of Fire Resisting Zones in passenger vessels. Such zones were to have 60 minutes fire resistance and were called "A" Class Divisions. In addition, cabin bulkheads were required to have 30 minutes fire protection and were referred to as "B" Class Divisions. In 1960 another Convention extended these regulations by requiring "B" Class Divisions to be installed in cargo ships of 4,000 tons and upwards.

Sprayed asbestos

When the treatment was introduced some 35 years ago, the spraying of asbestos fibre had been designed specifically for the thermal insulation of railway coaches, but it has long been recognised as providing a range of properties from thermal insulation and fire protection to noise reduction and condensation control. Moreover, this form of insulation material can be successfully applied by means of spraying to any shape or type of surface, usually without the need for mechanical support or extensive surface preparation (fig. 37).

Spraying is done with the aid of a specially designed adaptation of conventional pressure equipment. Certain types of asbestos fibre are blended with inorganic binders and are carried by a fine water spray on to the surface being covered. Initially the coating is in a semi-plastic state and special pressing tools may be used to cause it to follow the shape of the treated surface.

Tables illustrating the degree of fire-resistance given to steel beams and columns, solid reinforced concrete floors, timber floors, walls and other structures have been compiled by the Joint Fire Research Organisation as a result of tests done at the Fire Research Station. It is interesting and perhaps surprising to learn that an unprotected rolled-steel joist fails after exposure of 11 minutes under furnace tests conditions, whereas a similar joist, protected by $^5/_{16}''$ sprayed asbestos, has it resistance time increased to over one hour.

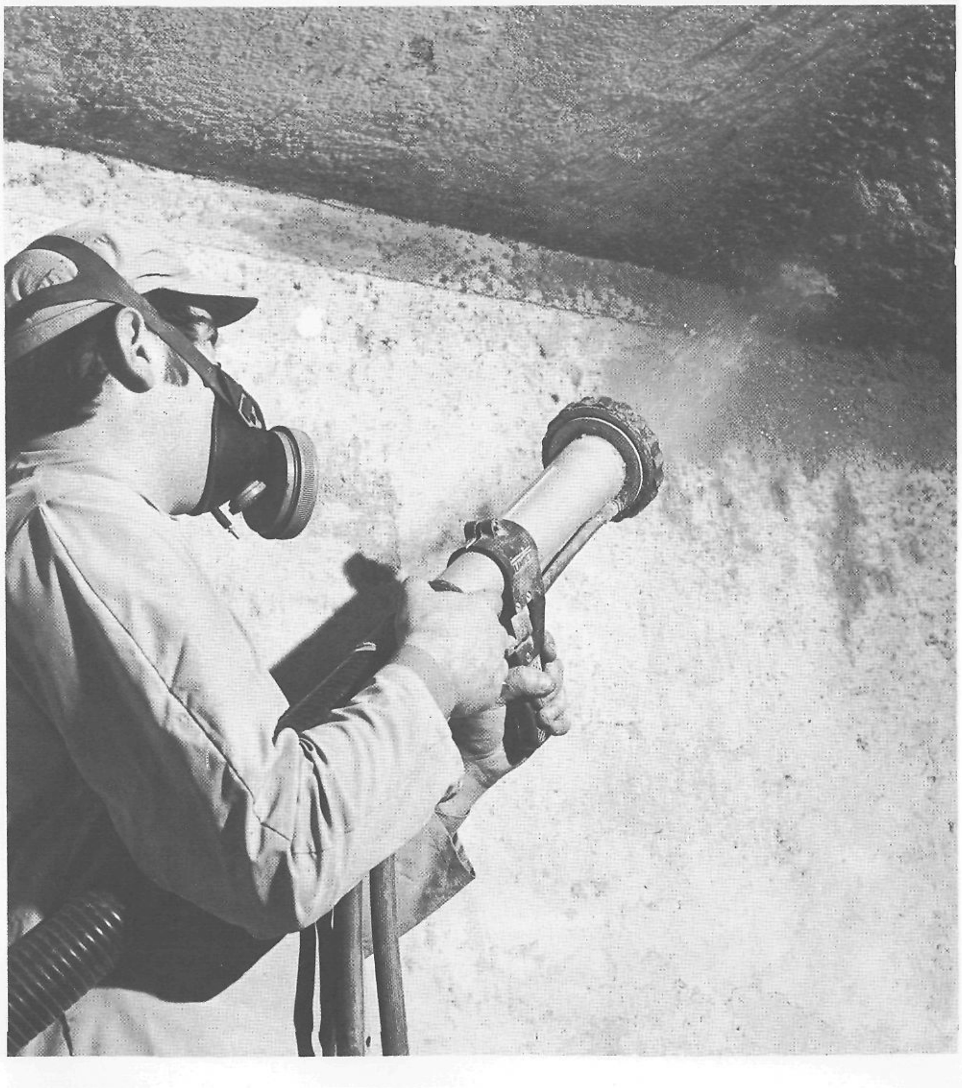
Sprayed asbestos is also employed on a large scale for planned sound control. It offers greater versatility than boards or tiles and is effective over a much wider frequency range.

Other benefits conveyed by sprayed asbestos include resistance to vibration, structural movement and adverse weather conditions. It is used to protect structural steel-work from corrosion and to provide large buildings with adequate thermal insulation, the purpose of the latter operation being to assist in maintaining comfortable ambient conditions, whilst at the same time reducing the cost of heating and air conditioning. Sprayed asbestos satisfies these dual requirements through the provision of a homogeneous coating of high thermal efficiency, reducing thermal losses and preventing the entry of cold air through sheeting laps and other gaps such as occur at ridges or eaves.

There are many industrial and community conditions in which condensation control is required as well as thermal insulation. High relative humidity exists in places such as dyehouses, public baths, laundries and kitchens, a consequence of which is that moisture tends to condense on internal surfaces, possibly leading to the corrosion of underlying steel framing. A sprayed asbestos coating of suitable thickness will keep the surface above dew point, and prevent condensation.

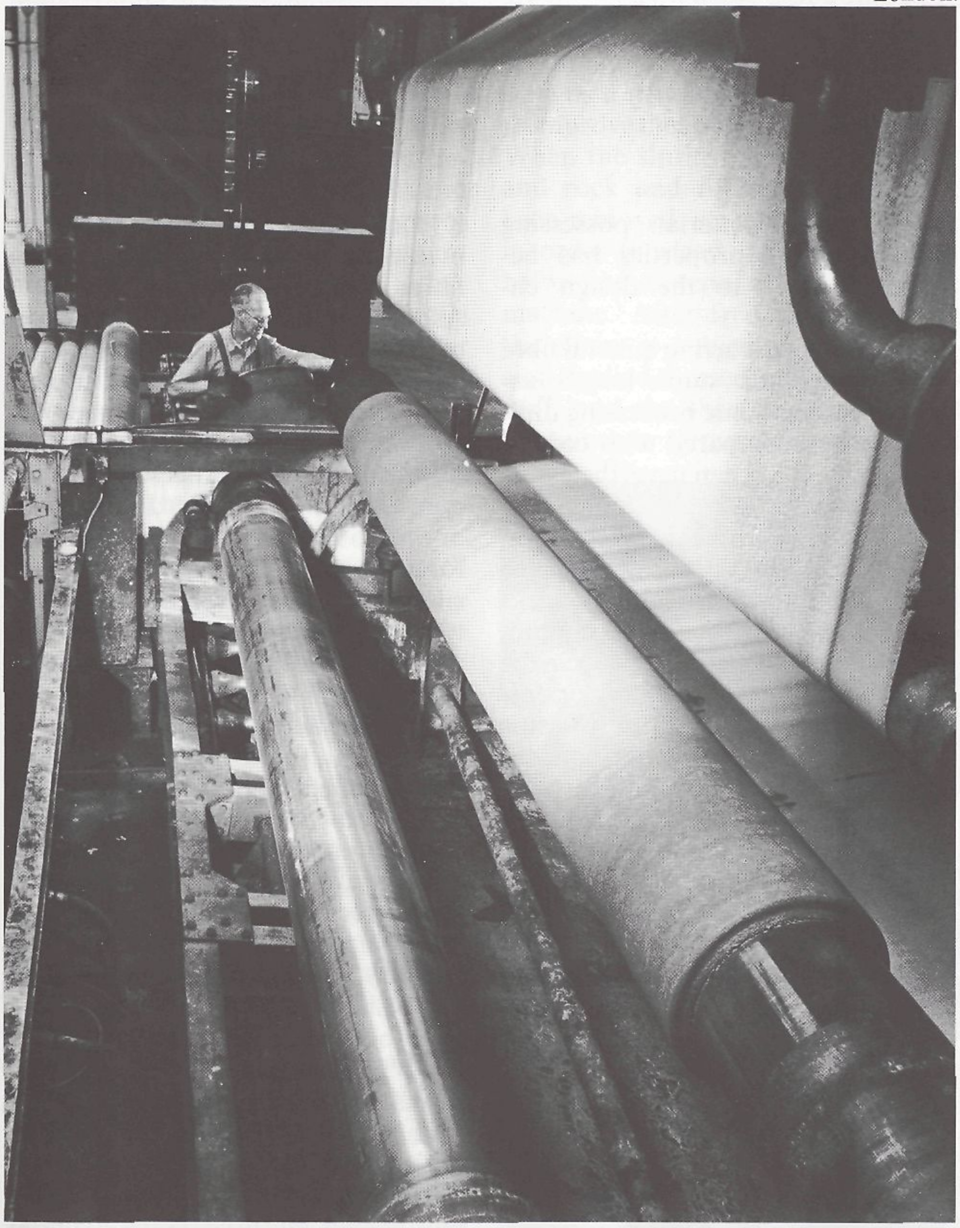
Asbestos-cement for pipes

Asbestos-cement is now regarded as one of the "traditional" pipe materials, having many uses, from pressure water mains to sewerage pipes,



37
The application of sprayed asbestos.
Photo: County Studios Ltd., Leigh, Lancs. (GB).

38
An asbestos-cement pressure pipe is shown leaving the production machine. The wall of the pipe is built up in laminate form on a polished mandrel.
Photo: Walter Nurnberg, London.



drainage pipes and cable conduits. Basically, the pipe is manufactured by a process similar to that described for sheeting, with the essential difference that the asbestos-cement film is transferred from a continuous felt not to a revolving drum but to a rotating mandrel. Successive layers are consolidated by the application of closely controlled hydraulic pressure over the whole length of the pipe. When the desired wall thickness has been obtained, the mandrel is withdrawn from the machine and the pipe from the mandrel. The pipe is subsequently "matured" by total immersion in a water tank for a week. It is then trimmed to length and turned at the ends (figs. 38, 39).

The advantages of asbestos-cement pressure pipes are numerous; in comparison with other traditional materials, they are light in weight; they possess the necessary mechanical and structural properties required of a water main; they have a smooth bore, low frictional resistance to flow, freedom from encrustation, constant carrying capacity, resistance to corrosion, flexibility in jointing and freedom from electrolysis. It is also possible to tap a water-carrying asbestos-cement pipe while the pressure is on and to redirect the water along a subsidiary main.

Asbestos-cement pipes for sewerage and drainage are designed in accordance with modern drainage practice for gravity carrying sewerage of a varying pH value and for conveying aggressive liquids resulting from industrial processes. While not immune to the adverse effects of concentrated acids, they are nevertheless particularly resistant to chemical action.

Other applications for asbestos-cement pipes are plentiful; they have been employed in mine drainage for carrying water containing free sulphuric acid, sulphates of iron, calcium and magnesium, and in circumstances where the pumping head exceeded 400 feet. Thousands of miles of electric cables have been laid in asbestos-cement cable conduits and troughs, and asbestos-cement pipes are widely employed as refuse chutes in multi-storey constructions.

Asbestos-cement products are versatile, essentially useful and often protective; there is no lack of competition in some areas but in others there is no known substitute for asbestos.

39
Threading pipe jointings on a lathe.
Photos 30–33, 36, 39: Eternit AG, Niederurnen (CH).

Asbestos in other spheres

W. P. Howard

Asbestos-reinforced plastics

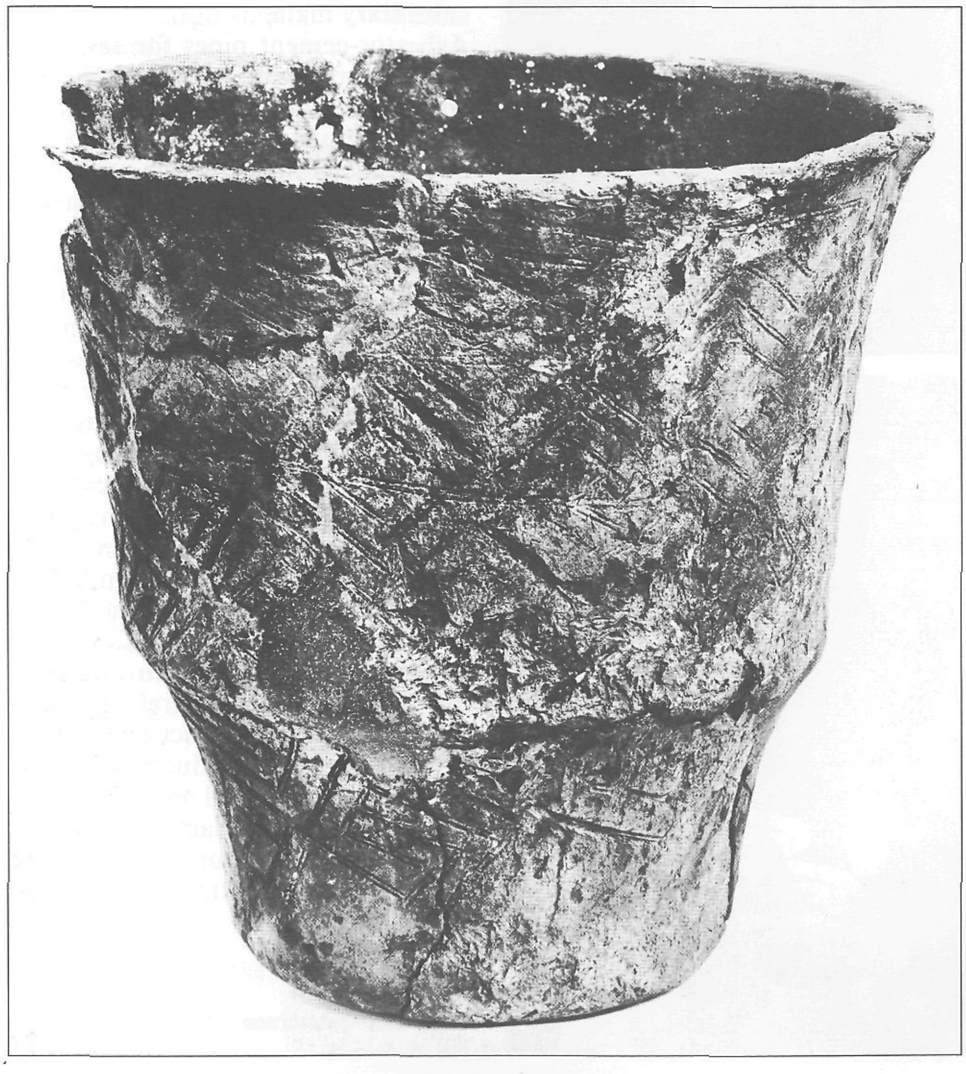
Modern industry needs materials endowed with light weight, great strength, dimensional stability, and good resistance to heat, chemicals and wear. While solid materials on their own very often do not provide this elusive combination of physical and chemical properties, fibre reinforcement has in many cases proved the answer. In the context of what might be described as "engineering plastics", the unique qualities and affinity for most resin systems of asbestos fibres have rendered them particularly attractive as a reinforcing agent. With the ever-increasing use of asbestos to reinforce both thermosetting resins and thermoplastics, a wide range of laminates and moulding materials possessing vastly differing properties has become available to the design engineer.

As a naturally occurring mineral fibre of relatively short staple length, asbestos presents some processing difficulties when compared with continuous filaments. It can nevertheless be subjected to carding, weaving and spinning and is employed in the form of yarns, cloths and tapes to reinforce thermosetting resins. Reinforcement can be achieved by the use of random fibres as flock, of felts in which the fibres have been directionally oriented through carding, and of asbestos papers manufactured by conventional paper-making techniques. But for the reinforcement of thermoplastics materials, which are primarily converted by means of injection moulding, only short-length random fibres are suitable.

Asbestos reinforcements in the form of felts, yarns, papers, cloths and tapes can all be resinated on continuous plant with speeds adjusted according to the thickness of the reinforcement being processed and the type of resin employed. After predrying to remove moisture, the reinforcement is impregnated by immersion in a resin bath and passed between nip rollers or doctor blades to aid impregnation and to eliminate surplus resin. It is then conveyed to a drying chamber for evaporation of the solvents used for resin dilution and to effect a partial cure of the resin. The temperature of the chamber and the speed of travel of the material are closely controlled to give the correct degree of pre-cure, and the resinated reinforcement emerges as a dry, semi-rigid sheet, which on most plants is automatically cut to size for use in the production of compression-moulded items such as sheets, tubes or rods.

In the case of felts, which cannot be subjected to rolling or drying on account of their flocculent nature, surplus resin is removed as the material passes over a vacuum table. Resination of the random fibre reinforcements used in moulding flocks or powders is carried out by dry resin mixing and ball mill techniques, after which the material is pelleted or preformed to reduce the bulk factor and to facilitate mould loading.

For the production of compression-moulded items, charges of resinated reinforcement, pre-weighed accord-

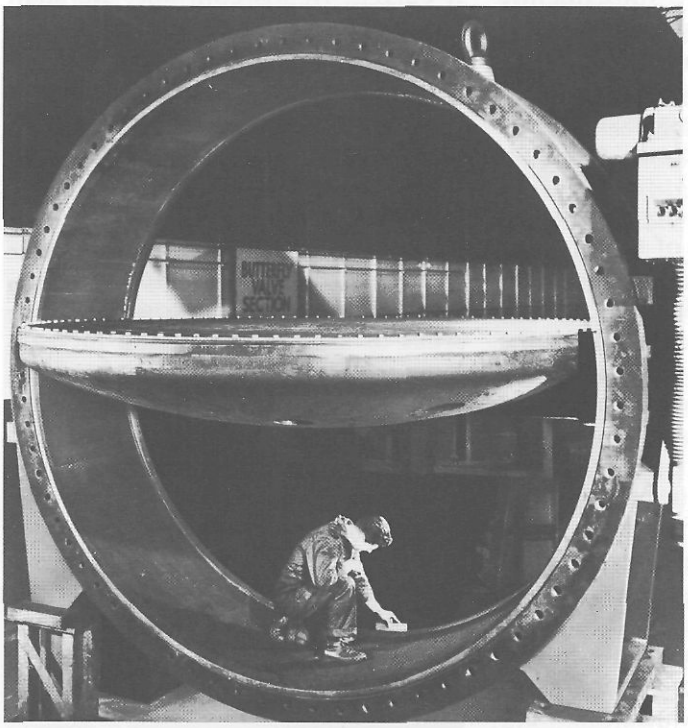


40
Asbestos vessel from the early Bronze Age, found on the Kvitstein River, Tysfjord, Norway.
Photo: Universitetets Oldsaksamling, Oslo.

ing to the thickness required, are introduced between polished press platens on single- or multi-daylight presses, which may be steam- or electrically-heated. Tubes or rods are formed by either manual or automatic rolling of pre-weighed amounts of resinated material, to which heat and pressure are subsequently applied in simple moulds.
Owing to their very limited flow properties, continuous asbestos reinforcements such as papers, felts and cloths are employed only for components produced by the compression moulding technique. On the other hand, flocks and powders can be moulded by compression, transfer or injection methods, although in the latter two processes the gates should be generous to avoid fibre orientation. Moreover, injection moulding is limited to short cure resin systems.
The properties of asbestos-reinforced thermosetting resins are impressive – high strength and load carrying capacity, good heat- and wear-resistance, low friction and an ability to accept almost any liquid as a lubricant.
Perhaps the largest single use for these materials is in the field of low friction wearing and bearing materials for applications in which relatively high surface speeds are combined with light loadings or low speeds with heavy loadings, or where lubrication by normal methods is difficult or impossible (fig. 41).
Other uses are in components subject to high impact stresses and in conditions where metal cannot be employed because of electrical considerations or corrosive environment. The spectrum of their applications is consequently enormous, ranging from roll neck bearings in steel rolling mills to hinge pin bushes for artificial limbs and ice cream liquidiser pump pisten heads.
The same combination of properties has led to the replacement of metals by asbestos-reinforced plastics for rotor blades in lubricated compressors and exhausters; and the exceptional heat- and flame-resistance of asbestos fibres is utilised in composites for such components as the nose cones, fins and Venturi tubes of guided missiles (fig. 42) and the heat shields of space modules and motor vehicles.

Asbestos papers

Asbestos papers, which have already been mentioned as one of the many types of plastics reinforcement, serve a multitude of needs throughout industry, especially in the electrical sector. The basic process whereby asbestos is manufactured resembles closely that for making ordinary cellulose paper. First, chrysotile fibres are mixed with water and a thin pulp or slurry is produced in a beater, at which stage a binding ingredient, such as a processed-starch, is added to improve the strength of the paper.
When the slurry has been prepared and rock and foreign matter have been removed, screening takes place in order to clean the stock further before the material enters the paper machine. After free water removal the slurry is subjected to compression applied through rollers or "presses", and the sheet thereby formed continues to a train of steam-heated cylinders to be dried. It is subsequently transferred to a re-reeler and slitter, where the required roll diameter can be built up and the edges trimmed to size.
The principal uses for asbestos papers and paper tapes are as spacing materials and heat insulation. Typical applications include high temperature flexible insulation in rotating electrical machinery and special heat- and arc-resisting linings in metal cabinets and cubicles.
However, asbestos papers can be treated, impregnated or combined with other materials to give a much wider variety of grades for different operating conditions. For example, the impregnation of asbestos papers with epoxy- or silicone-based varnishes imparts to the material better



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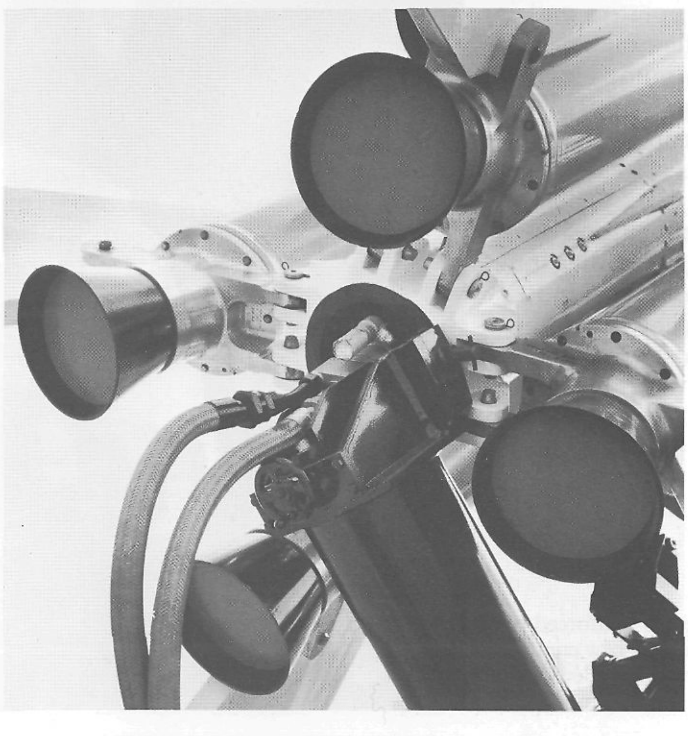
Butterfly valve in the cooling system of a power station. It is mounted on bearings made from asbestos-reinforced synthetic material.
With kind permission of English Electric Co. Ltd.



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Rocket blast tubes are moulded from asbestos-reinforced thermosetting resin compounds.
Photo: Raymond Irons, London.

electrical properties, while either varnish can be used to bond asbestos paper with glass cloth and thereby produce a composite possessing stronger mechanical properties than normal grades. Alternatively, one layer of paper may be bonded on either side of a special polyester film to produce a three-ply composite with greatly enhanced electrical and mechanical properties.

Resin-bonded asbestos paper laminates really come into the category of asbestos-reinforced plastics. Fundamentally, their method of manufacture follows the pattern described at the beginning of this article.

The rest of the process is concerned with lamination. The material is cut into squares and the desired number of layers built up on a cross-ply basis. Heat and pressure are subsequently applied in a multi-daylight press; the resin flows and the individual layers are bonded together.

A very similar process is used for the manufacture of cloth- and felt-based laminates.

The choice of resin depends upon the ultimate function of the product into which it is to be incorporated. Phenolic resin, first developed commercially by Dr. Baekeland at the beginning of this century, has a continuous operating temperature of about 130 °C., reasonably good electrical properties, and is able to withstand temperature extremes without loss of mechanical strength. For this reason, it is widely used in equipment subject to heavy shock loading and in circumstances where resistance to mechanical abrasion is required. More or less in the same temperature class is melamine, which has very good anti-tracking properties and is at the same time non-flammable. Silicone resin, with a continuous temperature performance around 220 °C., is used for those applications in which greater heat resistance is necessary.

Asbestos paper compositions also find their way in large quantities into the building and automotive industries. In the former, they are extensively employed as waterproof and weatherproof roofing felts. To make them, asbestos paper processed in the usual manner is impregnated with hot bitumen. The surplus impregnant is then doctored and a surface bitumen coating is applied together with various mineral fillers. In the automotive industry, many engine gaskets are based on asbestos beater jointing materials. In this case, the papermaking process differs in so far as it is a synthetic rubber latex composition (rather than a starch) that is added to the slurry as the binder. The type of rubber used depends upon the nature of the application and the special physical characteristics required.

Asbestos and the future

If current trends continue, we shall in years to come be relying on asbestos in many more ways than at present. In the first place, innovations such as the wet dispersion process for making asbestos yarn demonstrate that traditional asbestos products can, where necessary, still be improved to meet the more stringent requirements of modern industry. Secondly, the reinforcing properties of asbestos are being increasingly utilised in plastics composites, not just on the thermosetting side but in thermoplastics materials as well. Asbestos reinforced polypropylene is an excellent example of this. Although on the market for only two years or so, it is now widely employed in the manufacture of chemical plant process equipment, electrical mouldings (fig. 43) and the moulded parts of domestic appliances such as washing machines. Its use is also being extended to the "under-the-bonnet" components of motor vehicles.

It would probably be fair to say that the recent interest in carbon fibres has served to suggest fresh outlets for asbestos fibres, since it has focussed attention on properties of the latter which have not been fully exploited in the past. Carbon fibres are important because they combine stiffness greater than that of steel with only a fraction of the density. Asbestos fibres are also stiff and light and could perhaps be used in some of the technological applications for which carbon fibres are currently being considered, and in other fields. One significant factor is that although asbestos fibres are only half as stiff as the best carbon fibres available, they cost about one hundredth as much for a given increase in the stiffness of the final product. Asbestos is therefore much more likely to be used for those applications where large quantities of low cost structural materials are needed.

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Asbestos-reinforced polypropylene, a new composite material, moulded to form lamp-holders.

Occupational health factors in the United Kingdom

by H.C. Lewinsohn and S. Holmes

Asbestos dust, like the dust of many other basic industrial materials, can be a hazard to the health of people exposed to it in high concentrations. It is important that the risk should be clearly understood and that proper controls be exercised over the mining, manufacture and industrial use of the material.
An intensive study of this industrial hygiene problem has been carried out in the United Kingdom, where the most advanced government regulations for its control have recently been introduced. The Asbestos *Industry* Regulations were first introduced as long ago as 1931, and the pattern of control that has subsequently developed, culminating in the Asbestos Regulations 1969, has been an example to the rest of the world. This is because the British experience has shown that Regulations, where they have been properly applied, can be effective.
Three diseases have been associated with exposure to asbestos fibres. Asbestosis, a type of pulmonary fibrosis, is the result of inhaling high concentrations of fibrous asbestos dust, usually over many years, and a dose-response relationship has been established, i. e. the concentration of dust and duration of exposure determine the length of the interval between first exposure and the first recognisable signs of this disease. In 1968 the British Occupational Hygiene Society published standards for chrysotile asbestos dust, on the basis of which concentrations of less than 2 fibres/ml, averaged over 3 months, would be expected to reduce the risk of having early clinical signs of asbestosis to less than 1%, over a working lifetime of 50 years.
Lung cancer has been associated with industrial asbestos exposure. From clinical observation over the past 40 years it would appear that this complication is more likely to occur in the presence of severe asbestosis. Controls which are successful in reducing the incidence of asbestosis should therefore reduce the associated risk of lung cancer. American epidemiological work indicates the increased carcinogenic effects from smoking for asbestos workers. Asbestos insulation workers in New York who smoke appear to have a greater chance of dying from lung cancer than insulation workers who are non-smokers exposed to the same levels of dust.
Mesothelioma is a malignant tumour of the pleura or peritoneum. Medical opinion is uncertain with regard to the dose-response relationship in mesothelioma, though it may be contracted as a result of a much lower level of dosage than required for asbestosis. By no means all mesothelioma cases seem to be associated with asbestos. Evidence in Britain suggests that in about 10–15% of cases where the information has apparently been complete, no history of exposure to asbestos has been recorded. A recent survey of cases reported in Canada, however, could only trace an association with asbestos in 20%. In those cases where asbestos exposure has been authenticated, the period which elapses between first exposure and the onset of symptoms may be between 20 and 50 years.
Asbestosis can result from exposure to all commercially utilised types of asbestos, but is confined to those persons occupationally exposed to substantial amounts of asbestos dust. In Britain the number of confirmed new cases was 134 in 1969. This disease is more prevalent in workers employed in the insulation industry and in shipyards where the Asbestos Industry Regulations 1931 did not apply.
Where mesothelioma has been found to be associated with asbestos, the association has been mainly with crocidolite (blue asbestos). There are far fewer cases who have been expossed exclusively to chrysotile (this may account for the different incidence in the UK and Canada, which is the world's largest chrysotile producer). There are at present no authenticated cases of exposure to amosite or anthophyllite. The number of confirmed cases in Britain each year is about 60.
Mesothelioma has attracted considerable attention in recent years since it was first reported in association with exposure to N.W. Cape crocidolite in 1959. Some of these and some subsequent cases reported in London were of "neighbourhood" and domestic as opposed to occupational origin and it was assumed that these exposures had been to very slight concentrations of asbestos dust. Subsequent work, including dust measurements under conditions simulating some of the exposures described, has shown that these cases could well have been examples of considerable exposure. For example, in 1930 or earlier, a London woman brushing down her husband's dusty

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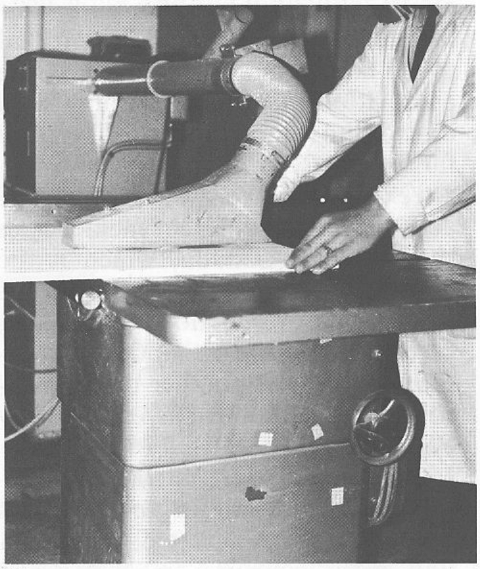
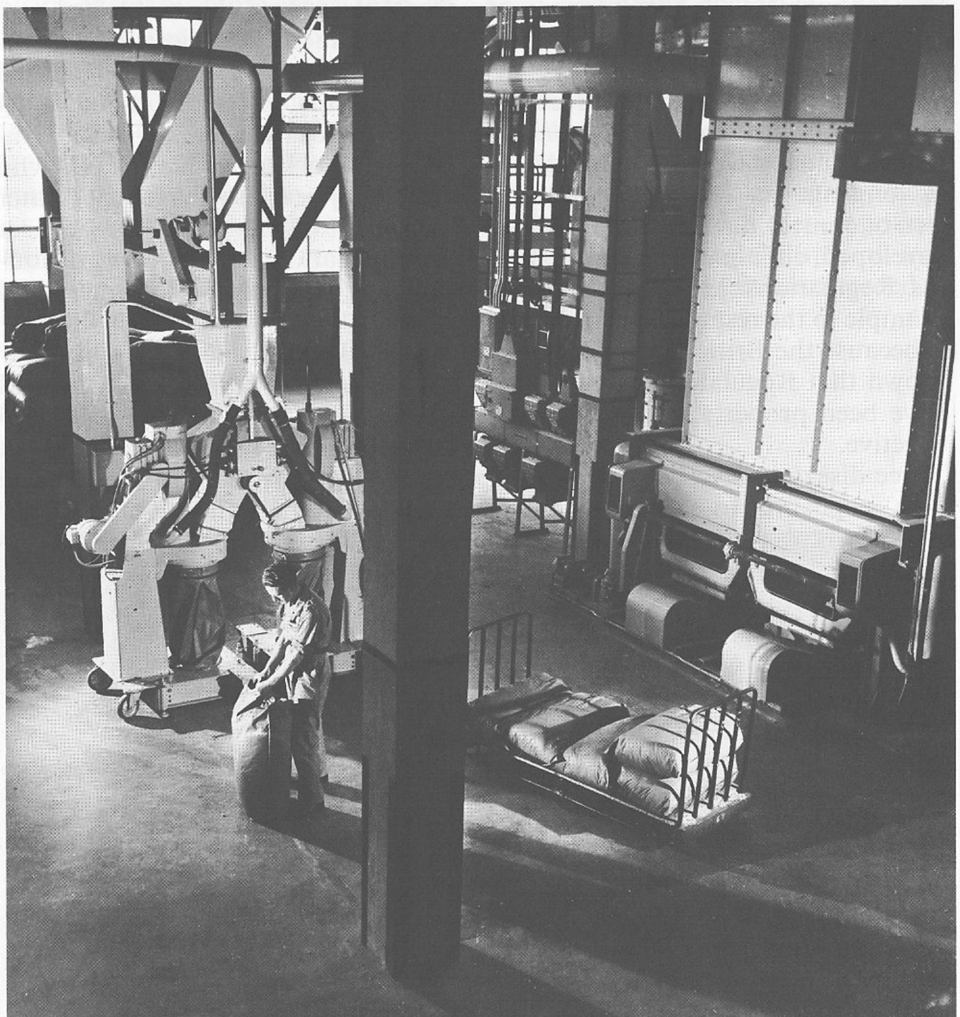
Portable suction equipment for use when drilling asbestos insulation board.
Photo: Owen Lawrence, London.



45
Circular saw fitted with suction equipment.



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Dust free storage and bagging of asbestos fibres.
Photo: Walter Nurnberg, London.

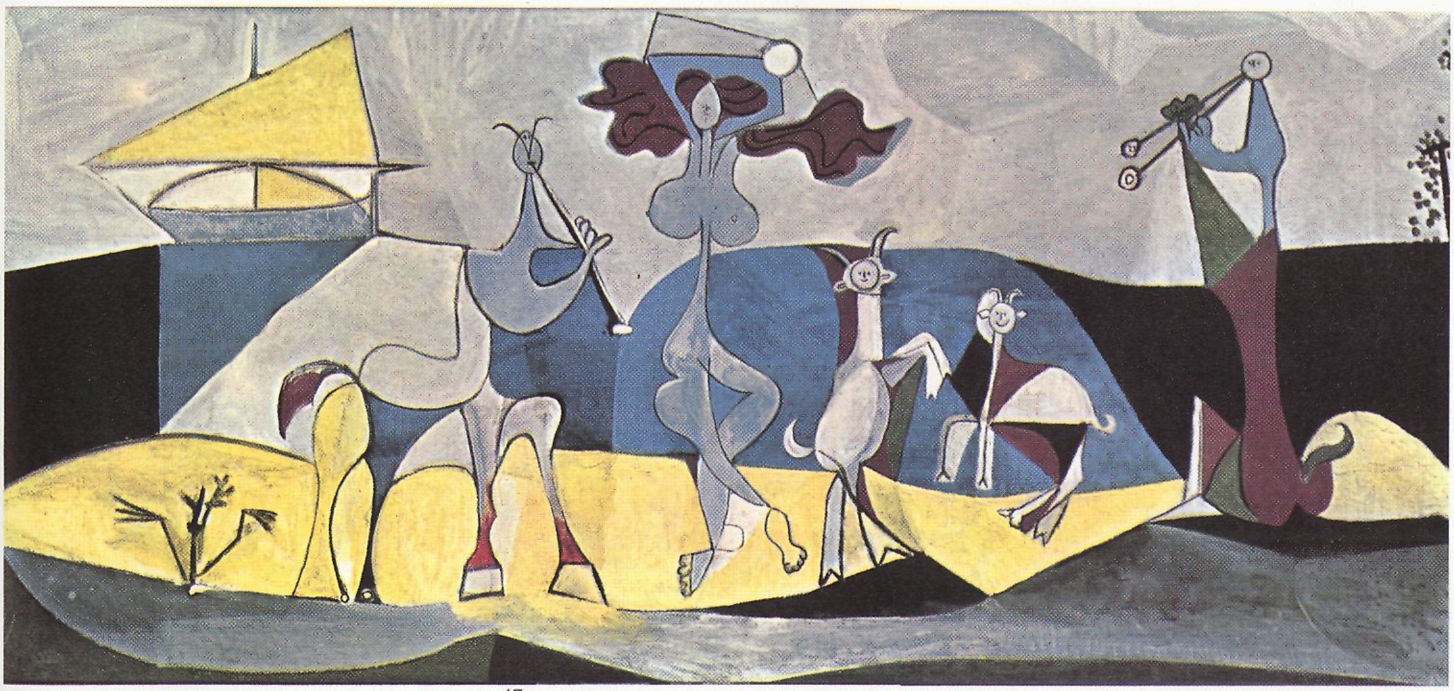
overalls on his return from work could well have been exposed to a far higher concentration of dust than has been permitted since 1931 in the factory where he was employed.

In South Africa more cases have now come to light in crocidolite mining areas of the N.W. Cape, but none have been confirmed among people exposed in the crocidolite mining areas of the Transvaal. No authenticated cases have been found among people exposed exclusively to amosite, which is mined in the same areas of the Transvaal and which has physical characteristics very similar to those of Transvaal crocidolite. This difference may be because blue fibre from the N.W. Cape is about 3 times finer in diameter than Transvaal blue and therefore more likely to reach the lung depths and penetrate to the pleura because of its sharp needle-like structure. Chrysotile fibres, which are long and curly, are intercepted in the bifurcations of the broncheolar subdivisions and amosite and crocidolite from the Transvaal do not penetrate as deeply because of their larger fibre diameters. This is a possible explanation of the means whereby certain fibres reach the pleura, but does not explain how the peritoneum is involved, except through further penetration through the diaphragm. There is no clinical or experimental evidence associating peritoneal mesothelioma with ingestion.

It is important to realise that the cases of asbestosis and mesothelioma being reported today are the result of exposure many years ago. There is a long latent period between first exposure and the first recognisable symptoms. These cases date back to a time when controls were not as effective as they are today in Britain. The Asbestos Regulations 1969 are now applied not only to asbestos factories, but to any occupation in which employees are exposed to concentrations of asbestos dust liable to endanger their health. Approximately 40 to 50% of the cases being diagnosed now are the result of work in the insulation contracting industry, which can involve very dusty jobs carried out in confined and badly ventilated spaces. Insulation work is subject to the Asbestos Regulations 1969, but was not adequately covered by the 1931 Regulations.

Acceptable hygiene standards are clearly set out in Technical Data Note 13 issued by H.M. Factory Inspectorate in the Dept. of Employment. There are many occupations to which the substantive provisions of the Regulations would not apply, because they do not give rise to dust above the recommended levels. Examples of these might be the handling of asbestos-cement sheets, the fitting of most asbestos-based packings and jointings, and the bonding of brake and clutch linings. The range of such applications is being steadily extended as more products, particularly in asbestos textiles, are produced in dust-suppressed grades.

Thus the essence of the British approach is to impose controls where dust levels could be dangerous to operatives and to restrict the use of crocidolite to essential purposes. Controls work. It has been shown in the asbestos textile factory where we ourselves work that the implementation of measures for dust prevention and personal protection since the early 1930s has reduced the incidence of lung cancer among our asbestos workers wholly employed since then to a level no higher than that expected for the population as a whole. Epidemiological studies at another British factory have shown no excess mortality among asbestos workers involved only in low or moderate exposure to asbestos dust.



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"Pastorale" by Pablo Picasso, 1946. Oils on asbestos cement, 120 × 250 cm.
From: Internationale Asbestzement-Revue (ac 28), October 1962.