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DUSTS PRODUCED DURING CUTTING OF MODERN SPLINTING BANDAGES

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Abstract

Previous work carried out by the authors (Wytch et al., 1988a) has shown that airborne dust generated during removal of orthopaedic casts with a power saw could represent a respiratory hazard. Further work has been carried out on all types of splinting bandage currently available in the United Kingdom to assess the potential dust hazard when sawing these materials. It has been shown that although plaster of Paris bandage produces significant concentrations of airborne dust, most of the polyurethane-impregnated fabric bandages generate extremely low levels of dust and in the case of the non-glass fabrics, the level is insignificant. However, it has been found that all types of splinting bandages generate particles small enough to reach the final divisions of the lungs. It is therefore recommended that a dust extraction unit is used when all types of splinting bandages are being removed with a power saw.

KEY WORDS: Dust, Splinting materials, Respiratory hazard, Microscopy, Orthopaedic fractures, Polyurethane, Synthetic bandages, Cast cutting.

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Introduction

Plaster of Paris (POP) bandage has been the pre-eminent external splinting material for the treatment of orthopaedic fractures for well over 100 years, primarily due to its excellent moulding properties, tolerance by the skin and low cost.

In spite of its popularity POP is not the ideal splinting bandage; it has a poor strength to weight ratio, a rapid loss of strength when brought into contact with water and it absorbs and scatters X-rays due to its crystalline structure which can adversely affect the definition of radiographs. It is messy in application, a mobile patient will have to use crutches for three days until a walking cast is fully cured, and even then POP casts frequently break when subjected to full weight-bearing. During cast removal with an oscillating power saw considerable dust is generated. To overcome these disadvantages of POP, numerous attempts have been made to find alternatives by impregnating various synthetic fabric bandages with resins.

Currently the most successful substitutes are fabric bandages impregnated with polyurethane (PU) resin. The most popular fabric presently used is glass fibre although cotton, polyester and polypropylene/Lycra are also available. All types of splinting bandage currently available in the United Kingdom, listed in Table 1 and illustrated in Figure 1, have been tested to assess the potential dust hazard when they are removed with a power saw.

These bandages are water-activated in a similar manner to POP but they can be weight-bearing within thirty minutes and are very much stronger, stiffer and lighter. They are widely used for constructing secondary casts, particularly weight-bearing casts.

Plaster room personnel have expressed concern over the potential hazards resulting from the use of these materials (Wytch et al., 1988b). These hazards include the isocyanates and other chemicals in the resin, the potential fire risk associated with polyurethanes in general (Ritchie et al.,1988), and the effects of the dust produced when casts are removed with an oscillating saw (Wytch et al., 1988a).

Many plaster room staff experience irritation around the wrist, hands, face and neck during cast removal. There is also

Table 1 MATERIALS TESTED FOR DUST PRODUCTION

Type of bandage	Product Name	Manufacturer
Cotton/ plaster of Paris	Gypsona	Smith & Nephew
Knitted glass fibre/ PU resin	Scotchcast Plus Dynacast Extra	3M Healthcare Smith & Nephew
Knitted cotton/ PU resin	Deltacast	Johnson & Johnson
Knitted polyester/ PU resin	Deltacast Plus Dynacast	Johnson & Johnson Smith & Nephew
Polypropylene & Lycra/ PU resin	Dynacast Pro	Smith & Nephew

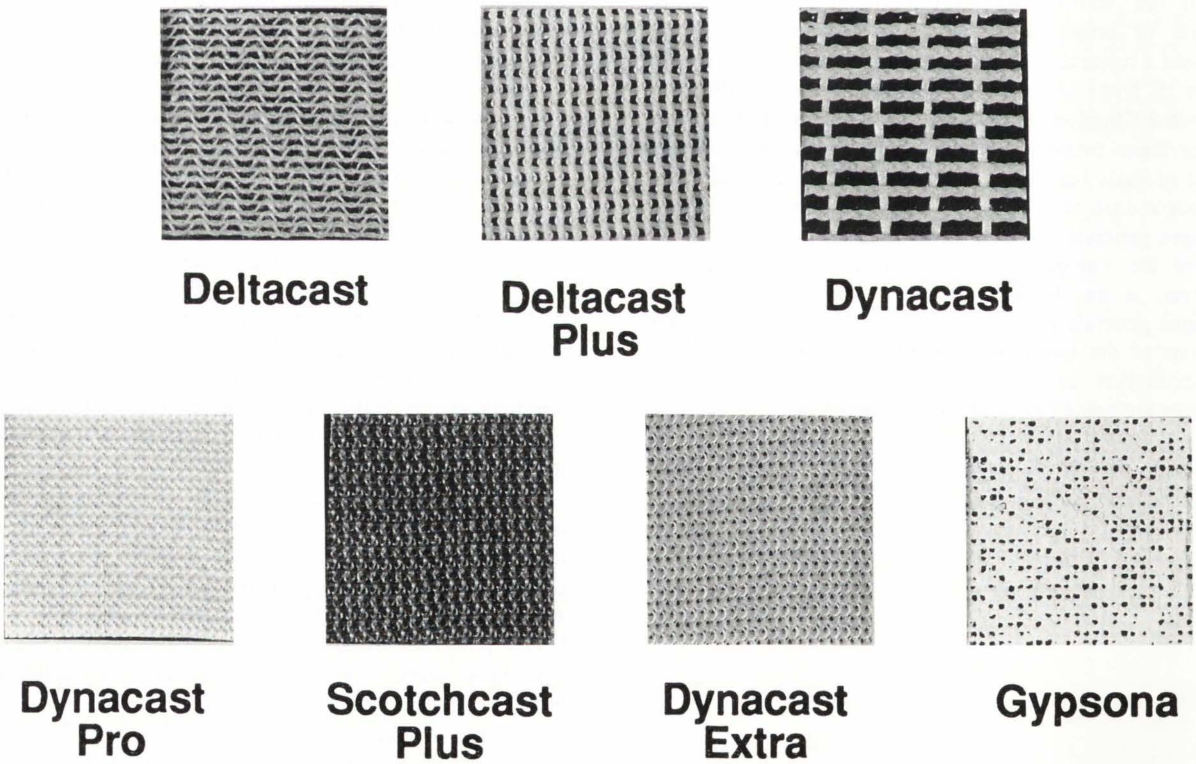


Figure 1 Photographs of bandages tested for dust production.

a reported incidence of corneal abrasions and various types of allergic reaction. These effects suggest that a fine cloud of dust is present during the sawing of these materials.

The high levels of POP dust generated during cutting can be observed in every hospital casting room. POP bandage produces sufficient dust to be classified as a nuisance dust by the U.K. Health and Safety Executive (HSE).

Dust was defined by the HSE (1986) as an aerosol of solid particles, mechanically produced, with individual particle diameters 0.1 µm upwards. Respirable dust is that fraction of the total dust cloud capable of reaching the final lung divisions and is defined by the "Johannesburg Curve" (Orenstein, 1960). For the purposes of optical counting, dust was classified as particles or filaments. Particles are defined as being essentially spherical in shape whilst filaments have a length to diameter ratio of greater than 3:1. The upper limit for respirability of man-made mineral fibre filaments has been defined as 3 µm diameter (W.H.O./Euro. Tech.Committee, 1985).

The effects of inhaled dusts after entry into the human respiratory system depend on the nature, size and concentration of the fragments. Occupational Exposure Limits have been defined for many individual dusts by the HSE (1990 edition of Guidance Note EH40). POP dust has been assigned an Occupational Exposure Standard (O.E.S.) of 10 $mg.m^{-3}$. Man-made mineral fibre (including glass fibre) has a Maximum Exposure Limit (M.E.L.) of 5 $mg.m^{-3}$. Both these limits are in terms of an 8 h time-weighted average exposure. No short-term exposure limit has been specified for either substance but it is recommended by HSE that in such instances a value of three times the 8 h limit be used for control purposes to apply to 10 min periods. Thus values of 30 and 15 $mg.m^{-3}$ respectively can be taken to apply. It should be noted that, because the sampling method employed differed from that specified for the determination of occupational exposure, (to enable a comparison between materials associated with the emission of low levels of dust to be made) the results obtained cannot be used for direct reference to Occupational Exposure Limits.

This paper reports on an investigation carried out to compare the airborne dust concentration and the nature and size of the particles produced during cutting of the splinting bandages using a power saw. The materials tested include POP, glass fibre with low tack PU resin (with added surfactant) and non-glass PU-impregnated products (see Table 1). The potential relative risk from airborne dust when cutting these materials is assessed.

Materials and Methods

Sample Preparation

All of the currently available types of PU-impregnated fabric bandages and POP bandage (see Table 1 and Figure 1) were compared for dust emission during cutting with an oscillating power saw. Bandages of each material 10 cm wide were activated according to manufacturers' instructions and formed into slabs 7 layers thick and 50 cm long. All slabs were prepared in an identical fashion. They were cured for 72 h under standard laboratory conditions, i.e. a temperature of 22(+/-1) °C and a relative humidity of 65(+/-2) %, before testing. Each slab was mounted on a foam block covered with fresh stockinette (to simulate normal cutting conditions) and secured with adhesive tape at either end.

Test Environment

Tests were carried out in a specially prepared room with a filtered air inlet in one corner and a high powered suction unit (Dronsfield) in the opposite corner, capable of providing 21 complete air changes per hour. Prior to each test the room surfaces were thoroughly cleaned with an industrial vacuum cleaner and purged using the Dronsfield suction unit until the particle count measured less than 0.3 particles ml^{-1} recorded by an electronic particle counter (Royco model 218).

Test Procedure

A 10 min test period for each sample was chosen intentionally to represent severe conditions when compared to a typical time for the removal of a below-knee cast of 5 min. Three samples of each material were subjected to 10 min of continuous cutting with an oscillating saw and the dust collected. To provide uniformity in cutting technique all were cut in an identical fashion with a series of parallel cuts. A new P.T.F.E.-coated chrome steel saw blade (Desoutter 16882) was fitted to the power saw (Desoutter C.C.1) prior to cutting the first sample of each material.

Dust Sampling

Three types of dust sample were taken during each test:

(a) personal sampling for total dust

(b) fixed position sampling for total dust and

(c) fixed position sampling for subsequent particle identification and size distribution using light and scanning electron microscopy (SEM).

The personal dust sampling head was attached to the lapel of the operator, and the fixed position dust sampling head was positioned directly in front of the operator 1 m away at head height. In each case, an open 25 mm diameter sampling head was employed with air being drawn through a glass fibre filter at a rate of 40 $l.min^{-1}$ using mains-powered rotary vane pumps to give a smooth airflow.

The fixed position sampling was in accordance with the HSE (1986) recommended method but the personal sampling was non-standard in that the airflow was 20 times the 2 $l.min^{-1}$ recommended. This was necessary to enable a significant weight of dust to be collected on the sample filter in the 10 min period for the synthetic bandages. Consequently the concentration values obtained from the personal sampling relate to total dust and not total inhalable dust and therefore cannot be used for direct reference to Occupational Exposure Limits. However, it is considered that the results obtained give a good indication of the relative dust emissions of the various materials.

Two further samples were taken to the right of the operator also 1 m away at head height, one for particle size distribution using light microscopy and the other for particle identification using SEM. The sampling head for light microscopy was fitted with a cellulose membrane filter with a pore size of 0.8 μm through which air was drawn at a rate of 10 $l.min^{-1}$ for all materials except POP where the rate was reduced to 2 $l.min^{-1}$ to allow for the greater volume of dust produced. This large reduction was insufficient to produce a particle density on the sample collection filter low enough to allow meaningful measurements to be made. The sampling head for SEM utilized a polycarbonate membrane filter with a pore size of 0.8 μm and a flow rate of 3 $l.min^{-1}$ for all materials except POP when a reduced rate of 2 $l.min^{-1}$ was used to allow for the greater volume of dust produced by POP. It should be noted that the collection of a particle on the sample filter is dependant upon the aerodynamics and density of the particle, the velocity of the air being drawn into the sampling device and possibly electrostatic effects. For particles having essentially identical aerodynamic characteristics and density, the effect of lowering the airflow rate will be that some larger (and hence heavier) particles will not be collected that would have been collected at the higher rate. However, the numbers involved at the higher (large diameter) end of the distribution will be low compared with those of smaller size and the effect of their omission from a cumulative percentage size distribution will be small. All that is likely to be affected is the upper limit of particle size of the distribution. It should also be mentioned that, because only 200 particles were sized on each sample there is a chance that in the random selection of filter areas for examination some larger particles could have escaped measurement.

Both light and electron microscopy samples were taken throughout the total test period of 30 min for each type of material.

Evaluation Techniques

Gravimetric - Personal and fixed position dust samples were evaluated using simple gravimetric techniques similar to those given by HSE (1986). Airborne dust concentrations are determined by passing a known volume of contaminated air through a filter of predetermined weight. By reweighing the filter at the end of the sampling period, the concentration of total dust was found by dividing the weight gain by the volume of air passed through the filter and is quoted in $mg.m^{-3}$ of air.

Particle size distribution - Standard light microscopy techniques were used to determine the size distribution of 200 particles and the length of 50 filaments collected on cellulose membrane filters. These filters were rendered transparent by exposure to a stream of acetone vapour and the deposit sealed by the addition of a cover glass secured by glycerol triacetate. They were examined under bright field conditions at an overall magnification of 400 x. The dust particles collected on the sample filters were likely to have consisted of more than one component of different density in varying and unpredictable proportions which could not be determined. Consequently no attempt was made to classify particle size in terms of aerodynamic diameter. However, to give an indication of the potential respirability of the dust, the upper limit of the Johannesburg Curve (7 µm) was selected as a convenient reference point.

SEM Methods

For electron microscopy samples of bandage fabric and segments of polycarbonate filters with attached dust particles were mounted on stubs with colloidal silver adhesive, sputter-coated with platinum and examined in a Jeol JSM-35CF scanning electron microscope at 10 kV. X-ray dot mapping samples were mounted as above but were coated with carbon from an electron beam source and analysed using a Link Analytical AN10/55S X-ray microanalysis system.

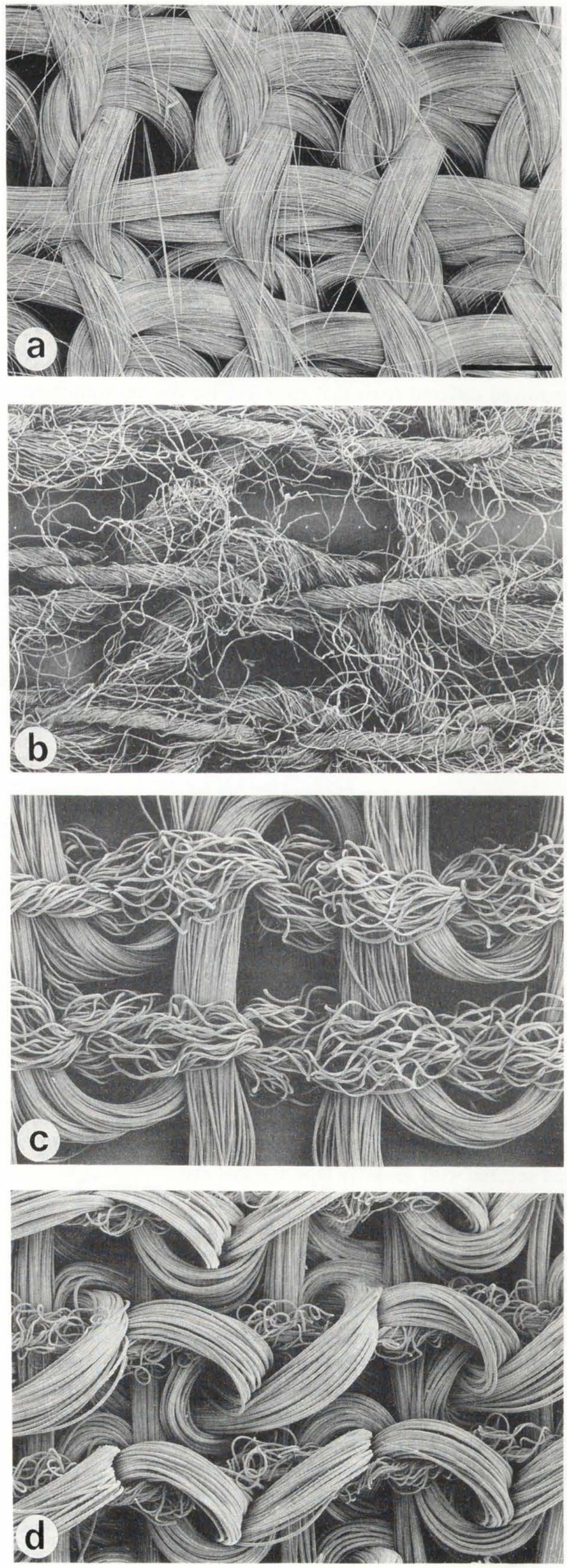


Figure 2 Scanning electron micrograph showing the knitted pattern of the following bandage fabrics: (a) Dynacast Extra (glass fibre) (b) Deltacast (cotton), (c) Deltacast Plus (polyester) and (d) Dynacast Pro (polypropylene and Lycra). Bar line (for all 4 figures) = 1mm.

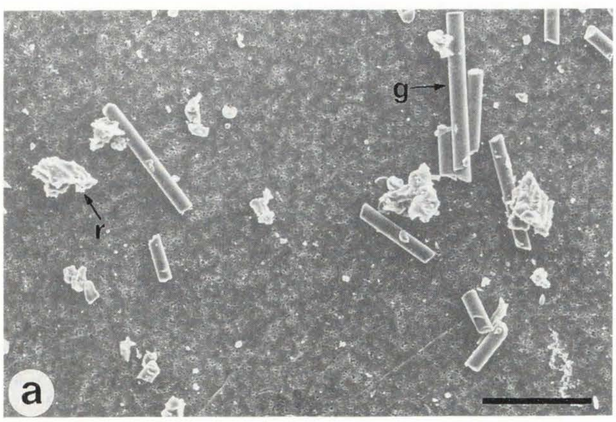
Results and Discussion

The electron micrographs in figure 2 show samples of the bandage fabrics which are knitted from bundles of synthetic filaments called fibres. They illustrate the variation of knitted patterns used in the different types of synthetic bandages tested. It is the knitted structure of these bandages that gives them the necessary flexibility and conformabilty which, combined with their strength, makes them suitable for use as splinting materials.

Table 2 AIRBORNE DUST CONCENTRATIONS ($mg.m^{-3}$)

	Personal	S.D.	Fixed position	S.D.
Plaster of Paris	35.5	1.5	17.1	2.9
Glass fibre	1.2	1.0	0.7	0.6
Cotton	<0.4*	-	<0.4*	-
Polyester	<0.4*	-	<0.4*	-
Polypropylene	<0.4*	-	<0.4*	-

* not significant S.D. = Standard Deviation



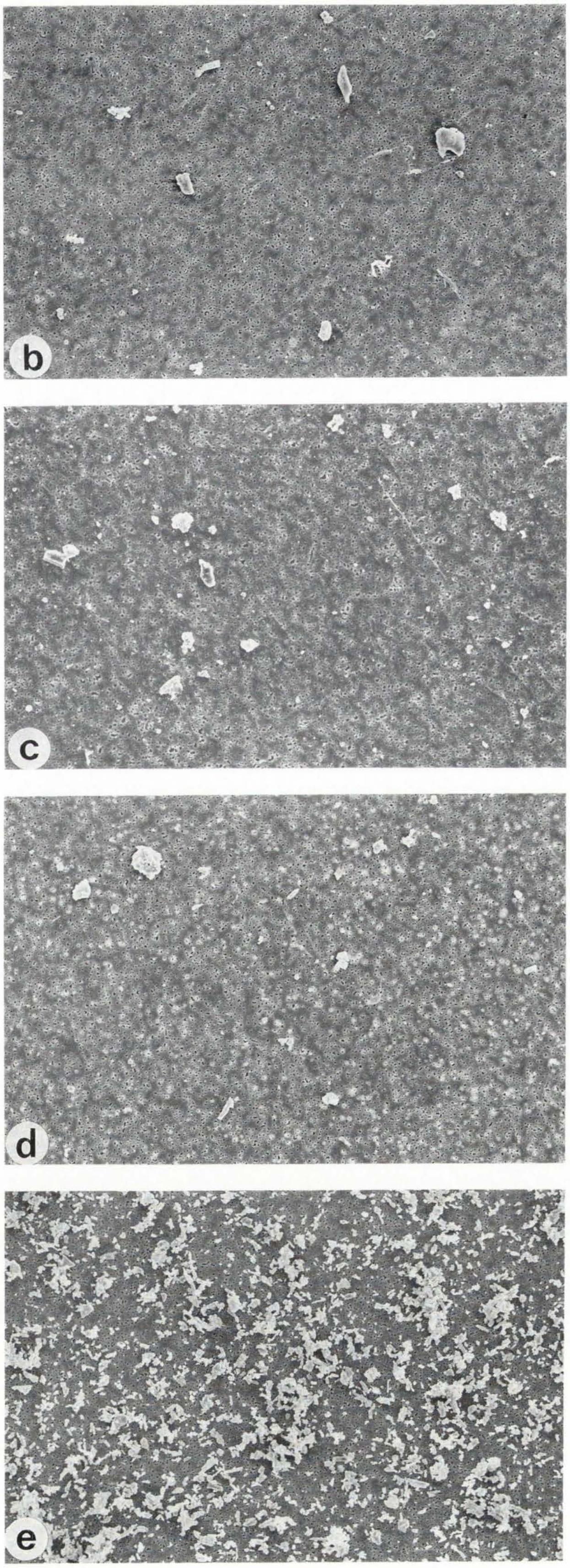


Figure 3 Scanning electron micrographs showing typical samples of dust collected on Nucleopore polycarbonate filters during sawing of the following PU-impregnated splinting bandages: (a) Dynacast Extra (glass fibre fabric), g = piece of glass filament, r = amorphous particle of resin, but which may also contain fragments of glass (see figure 4). (b) Deltacast (cotton fabric), (c) Deltacast Plus (polyester fabric) (d) Dynacast Pro (polypropylene and Lycra fabric) and (e) Gypsona (plaster of Paris) Bar line (for all 4 figures) = 50μm.

Table 2 shows the airborne dust concentrations for POP (35.5 mg.m^{-3}) were very much higher than those from the synthetic bandages. Glass fibre bandages generated very low levels of dust (1.2 mg.m^{-3}) whereas the three non-glass fabrics (cotton, polyester and polypropylene/Lycra) did not produce significant levels of dust. The personal sample was always higher than the fixed position sample and shows that personal sampling is a more critical measure of the airborne dust concentration to which a person is exposed.

The electron micrographs in Figure 3 show examples of the quantities and types of dust collected on the polycarbonate filters. These were either fabric filaments or resin particles, or aggregates of resin and filament material. In the case of the glass fibre bandages, where the fabric glass is composed of characteristic elements not present in the resin, it was possible to use dot mapping of the X-ray signal to indicate which dust fragments contained glass. An example of this is illustrated in Figure 4. It is clear that in addition to the obvious glass filaments, some of the amorphous particles also contain fragments of glass - a finding which could not be deduced from shape alone. This suggests that some particles may be capable of causing abrasion to the epithelium of the respiratory tract and may also cause fibrosis (Waldron, 1980).

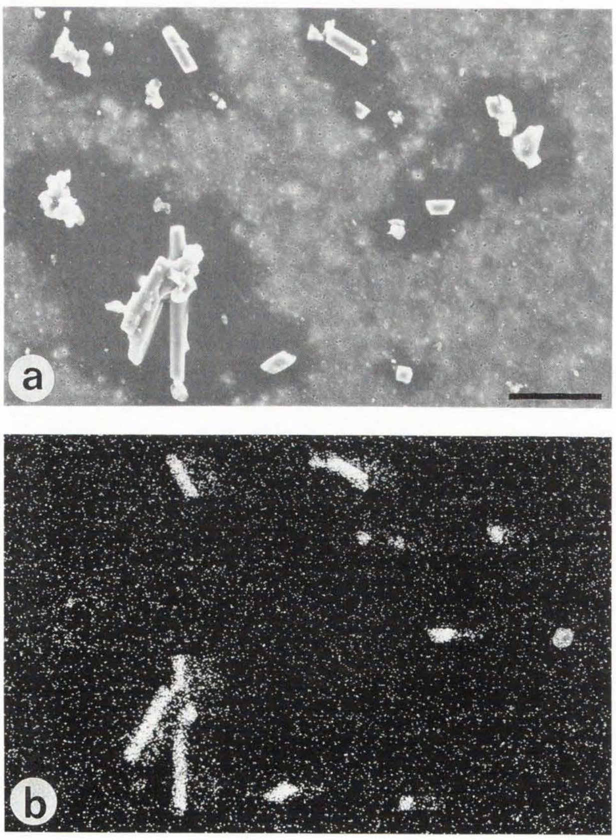


Figure 4 (a) Scanning electron micrographs showing a typical sample of dust collected during cutting of Dynacast Extra, a PU-impregnated glass fibre fabric bandage. (b) an X-ray dot map of the same area shown in (a) produced by the SiK and CaK X-rays generated from the glass component. Bar line (for both figures) = 50µm.

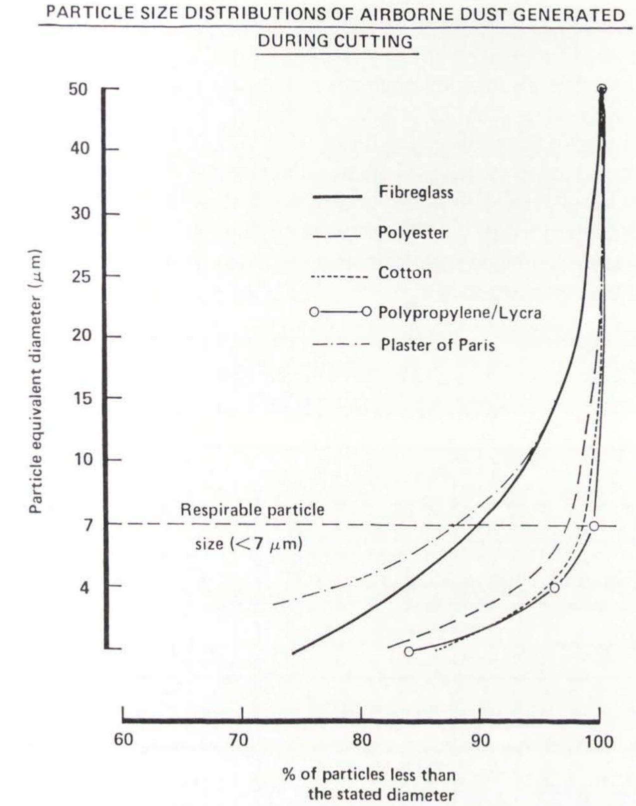


Figure 5 Particle size distribution of airborne dust generated during cutting of the plaster of Paris and synthetic bandages.

The particle size distributions for dusts from POP and PU-impregnated bandages were similar as shown in Figure 5. It can be seen that more than 90 % of the particles were potentially respirable if the upper limit for their respirability is taken as 7 µm (Orenstein, 1960). However, for man-made mineral fibre filaments, the upper limit for respirability has been defined as having a diameter of 3 µm (W.H.O./ Euro. Tech. Committee, 1985). For the glass fibre bandages, all airborne dust filaments had diameters greater than this limit and lengths varying from 8 µm to over 100 µm.The dust filaments from non-glass bandages were typically very long and convoluted (making it difficult to determine their length accurately).

Conclusions

Cured PU resin is a stable compound and glass, cotton, polyester and polypropylene/Lycra are chemically inert so the potential fibrogenic effects (Waldron, 1980) from these substances depend on whether dust is able to reach the alveoli. This study has shown that during removal of orthopaedic casts with a power saw, the PU-impregnated bandages produce very much lower (less than one thirtieth) concentrations of dust than POP. However, it has also been shown that over 90 % of the particles in the dust cloud are potentially respirable and that these contain fragments of PU resin. There are no Occupational Exposure Limits for polyurethane dust, but the absence of a limit does not imply that this type of dust is inert.

The filaments produced by sawing the synthetic materials are too large to reach the final divisions of the lungs and are unlikely to produce a respiratory hazard. Nevertheless these filaments are thought to be the cause of skin and eye irritations experienced by some plaster room staff.

To minimise the inspiration and irritation of dust experienced by orthopaedic personnel, we recommend the use of a dust extraction unit when cutting all types of splinting bandages with a power saw.

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Discussion with Reviewers

J. Wasserman: It would seem to me that the accuracy of measuring particles using SEM instead of a light microscope would be greater. Would you care to comment on why you took no measurements using ultrastructural methods. Do you think there would have been some virtue in at least comparing measurements obtained by the two methods?

Authors: We agree that measurements using SEM would have greater accuracy. However, the light microscope analysis quoted in this paper was carried out by a commercial organisation using trained operatives who undertake this type of dust analysis full time. In the present comparative study any measurement errors are likely to be similar for all materials.

J. Wasserman: What short or long term effects, other than fibrosis, result from acute or chronic exposure to "respiratory hazards"? The results of exposure to asbestos are well known. Would exposure to the dust particles described in your report produce similar effects?

Authors: The effects of inhaled dust may be categorised as toxic, allergenic, fibrogenic, carcinogenic or inert. We do not have specific information on the hazards of the materials described in this paper.

D. J. Pratt: Do the authors have any figures which indicate the efficacy of dust extraction units and the change in nature of the dust that remains in the air, assuming these units are not 100 % effective?

Authors: No tests have been carried out and therefore no figures are available.

D. J. Pratt: In the absence of a dust extraction unit on power saws, is there an argument for insisting upon additional protective goggles/masks for staff regularly using these materials?

Authors: When using a power saw to remove bandage type casting materials, it is strongly advised that goggles/masks should be worn by plaster room staff.

T. L. Ogden: The authors appear to have identified a real matter for concern, but the work has a basic flaw in that the authors used a highly non-standard sampling method for the personal sample, namely 40 l/min through an open filter holder, instead of 2 l/min through a head designed to give the total inhalable fraction at that flowrate (HSE, 1986). The results therefore cannot be compared with the UK exposure limits for total inhalable dust because aerodynamic effects will mean that the fraction collected must differ from total inhalable to an unknown degree.

Authors: This paper presents a comparative study of dust emissions of splinting bandages during cutting; we did not intend to determine absolute dust levels which would comply with Health and Safety standards.

T. L. Ogden: The refractive index of the materials collected might affect their visibility if their r.i. was close to that of the cleared membrane. Was it?

Authors: The materials collected had refractive indices of >1.54 and that of the filter/mountant combination was 1.44. Therefore the difference in the refractive indices was sufficient to ensure that the dust from the bandages were clearly visible using light microscopy.