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Fabricating fungi

Dr Paul F Hamlyn
British Textile Technology Group

This is probably the greenest article we are ever likely to have as it envisages growing fibres. Creating new nonwovens and using them as filters to recover valuable metal compounds is an exciting new concept, but added to this is the prospect of new medical textiles with special wound-healing properties. Looking at the concept long term and introducing genetic engineering, the thought of 'growing' synthetic leather is far from being far-fetched.

Dr Paul F Hamlyn, MI Biol, PhD, C Biol, joined the British Textile Technology Group (then Shirley Institute) in 1982, following three years' postgraduate research work at the University of Nottingham on the genetics and physiology of fungi. He previously worked in the pharmaceutical industry as a microbiologist. Section head of molecular biology and fermentation in the biology department, his current research projects at BTTG are concerned with applications of biotechnology in the textile industry.

Innovation in fibre technology in recent years has focused on synthetic fibres, with a few exceptions, such as PHB, alginate and bacterial cellulose. This article summarises a programme of work carried out at BTTG to investigate the potential applications of novel materials based on microfungal filaments.

Fungi are a diverse group of microorganisms, and include the higher fungi characterised by their large fruiting structures (such as mushrooms), and the lower microfungi more commonly known as moulds. The idea of fabricating something useful out of a fungus is not new. It was formerly the custom in some European countries to make a sort of suede from the fruit-bodies of certain forest fungi, and to use the material to fashion hats. More recently, Ranks Hovis McDougall PLC in partnership with ICI have developed a totally new foodstuff called mycoprotein (trade name Quorn) derived from microfungal mycelium, which because of its fibrous nature has a composite texture resembling lean meat.

From the textile point of view, microfungal filaments have several useful attributes in comparison with conventional natural fibres. It is easy to grow: the biomass is available in days rather than months. It also has a novel cell wall chemistry, based on chitin rather than cellulose or keratin, and different kinds

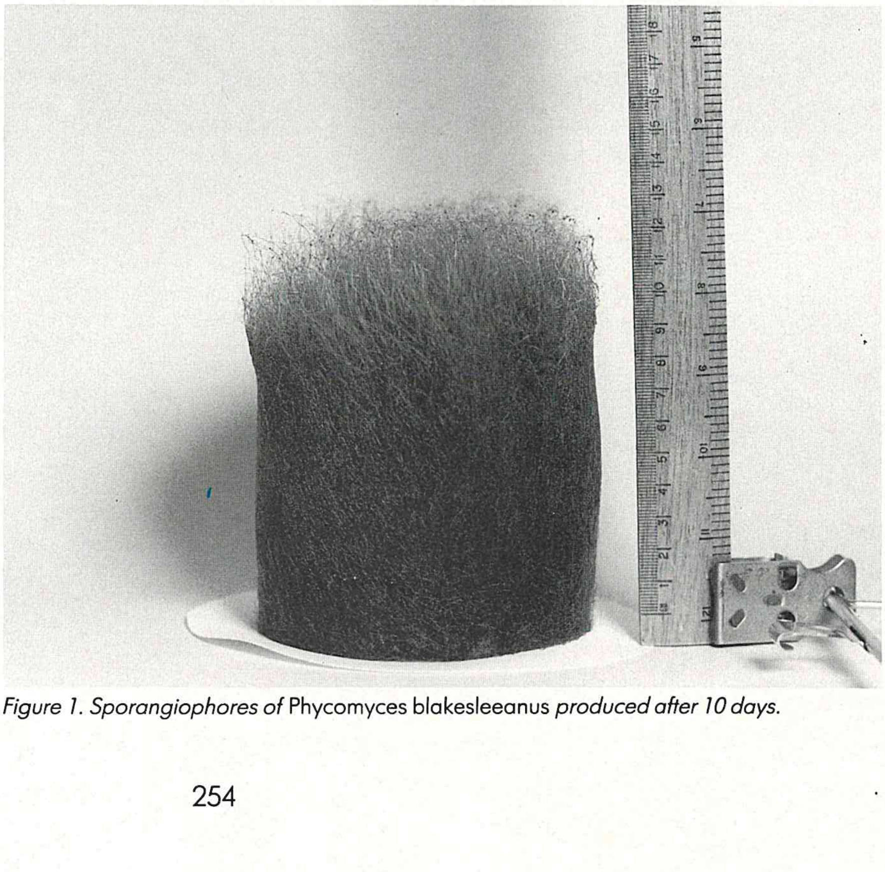

Figure 1. Sporangiophores of Phycomyces blakesleeanus *produced after 10 days.*

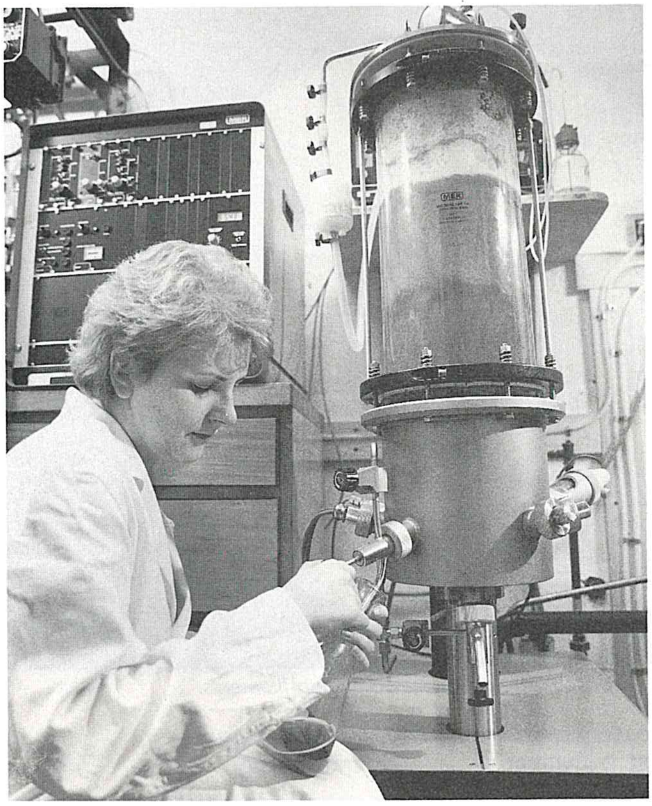

Figure 2. Pilot-scale 20 litre bioreactor.

Figure 3. Preparation of wet-laid mats from microfungal filaments using a British Standard Sheet Paper-making Machine.

of filamentous structures are available, ranging from straight fibres several centimetres in length (sporangiophores) to branched microscopic filaments (mycelium).

Leaving aside the fruit bodies and other specialised structures of higher fungi, microfungi are composed of two basic types of filamentous structure; the vegetative thallus or mycelium and various spore-bearing reproductive structures such as sporangiophores (Figure 1). Sporangiophores are only obtained on solid substrates similar to those employed for mushroom cultivation, whereas vegetative mycelium can be produced most economically on a liquid growth medium inside a bioreactor (Figure 2).

The liquid medium will typically contain inexpensive or waste materials such as molasses, hydrolysed starch, corn steep liquor and inorganic salts. From a commercial point of view the technology for growing a fungus in a bioreactor is well established. Industrial bioreactors of over 1 000 000 litres in volume are now used for the production of biomass.

Fabrication

After growing a fungus in a bioreactor the resulting broth contains very fine branched filaments which, after suitable processing, can be fabricated in several different ways. The broth is first filtered through a fine mesh filter and thoroughly washed with water to remove re-

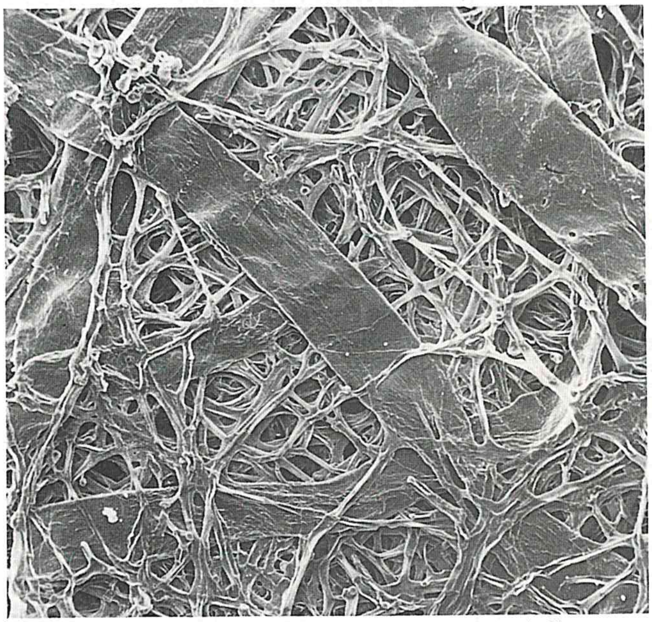

Figure 4a. Composite mat of microfungal and wood pulp fibre.

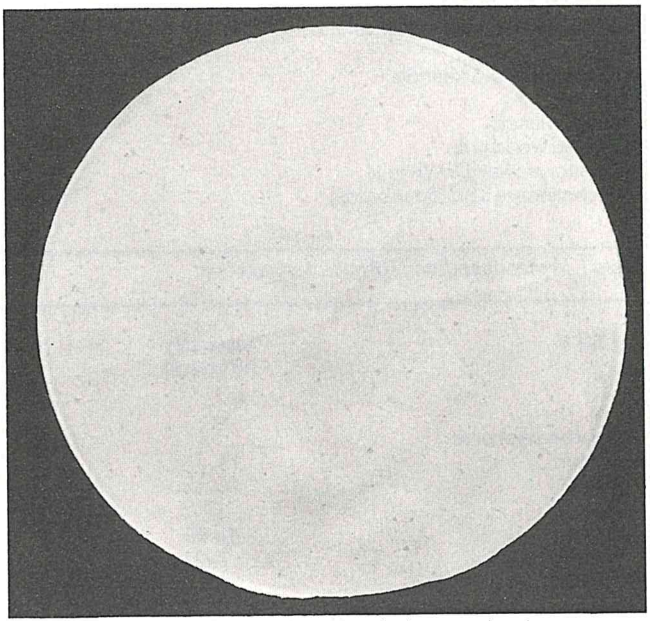

Figure 4b. Scanning electron micrograph showing the ultra structure of the mat's surface (magnification 550X).

sidual medium constituents. Depending on the end-use, alkali treatment can be employed to remove proteins and other impurities and the filaments can be bleached to give a white product. The treated filaments are again thoroughly washed and finally re-suspended in water.

At this stage the filaments can be wet-laid, either on their own or mixed with conventional fibres such as wood pulp and polyester using normal laboratory paper-making equipment (Figure 3). When mixed with other fibres, the resulting composite mats are coherent but paper-like (Figure 4). On their own the microfungal filaments give very brittle structures. However, these can be plasticised (for instance with glycerol) to form flexible, membrane-like materials. Another type of novel material can be made by freeze drying a thick slurry of the filaments to produce an absorbent pad (Figure 5). The water absorbency of this type of product compares favourably with conventional absorbent materials (Table 1).

Figure 5. Absorbent pact composed of freeze-dried microfungal filaments.

In the case of the sporangiophores, attempts to spin a yarn from these long straight filaments have, so far, proved unsuccessful due to their brittle nature. Sporangiophores suffer from the dual drawback of having both a low tensile strength and breaking extension in comparison with conventional natural textile fibres (Table 2). Therefore, it was only possible to fabricate these filaments by the methods already described after they had been cut into suitable short lengths to aid dispersion.

We have considered a number of potential end-use applications for micro-fungal nonwovens:

- Low value
  - Wet wipes/absorbent materials
  - Binding agents for conventional nonwovens
  - Filtration products
- High value
  - Artificial leather
  - Metal-ion bisorption
  - Wound healing

Sample	**Water Absorbency (g per gram of sample)**
Microfungal Pads	
Aspergillus oryzae	17.5
Mucor mucedo	10.5
Rhizomucor miehei	14.2
Phycomyces blakesleeanus	16.3
Conventional Materials	
J Cloth	7.6
Cotton linters	13.4
Fluffed wood pulp	12.6
Sanitary towel (Dr White's)	13.1
Incontinence pad (Boot's aids)	18

Table 1. Water absorbency of microfungal pads.

Fibre	**Tenacity (cN/tex)**	**Breaking extension (%)**
Sporangiophores	7	3
Cotton	19–45	6–9
Wool	11–14	30–43
Flax	57	3
Jute	31–70	2
Viscose rayon	7–27	16–27
Casein	10	63

Table 2. Tensile properties of sporangiophores and some conventional textile fibres.

Because of their absorbent properties microfungal nonwovens appeared to have some potential as wet-wipes, or as components of sanitary materials. It was also found that relatively small proportions of mycelium (five per cent) can act as a binding agent, improving both the dry and wet tensile strength of conventional wet-laid nonwovens (such as speciality papers), probably due to the enhanced H-bonding characteristics of microfungal filaments.

Composite mats produced by blending different proportions of mycelium and conventional fibres (such as polyester) can be formulated with pore sizes down to about four microns. Some of these mats were found to have filtration characteristics comparable to commercial filters. This property relates to the fineness of the microfungal filaments (about two to eight microns in diameter depending on the species).

Although these results were encouraging the commercial potential for new materials is obviously largely dependent on the cost of their production. Products such as disposable wet-wipes entail the manufacture of large quantities of material at low cost. Other applications require smaller amounts of biomass, and the nature of their uses is such that the market in these instances can realistically be regarded as being able to support a high value product.

Even with future improvements in bioreactor design it is unrealistic to expect that microfungal biomass will ever be able to compete on a cost basis with materials such as wood pulp or glass fibre found in many conventional

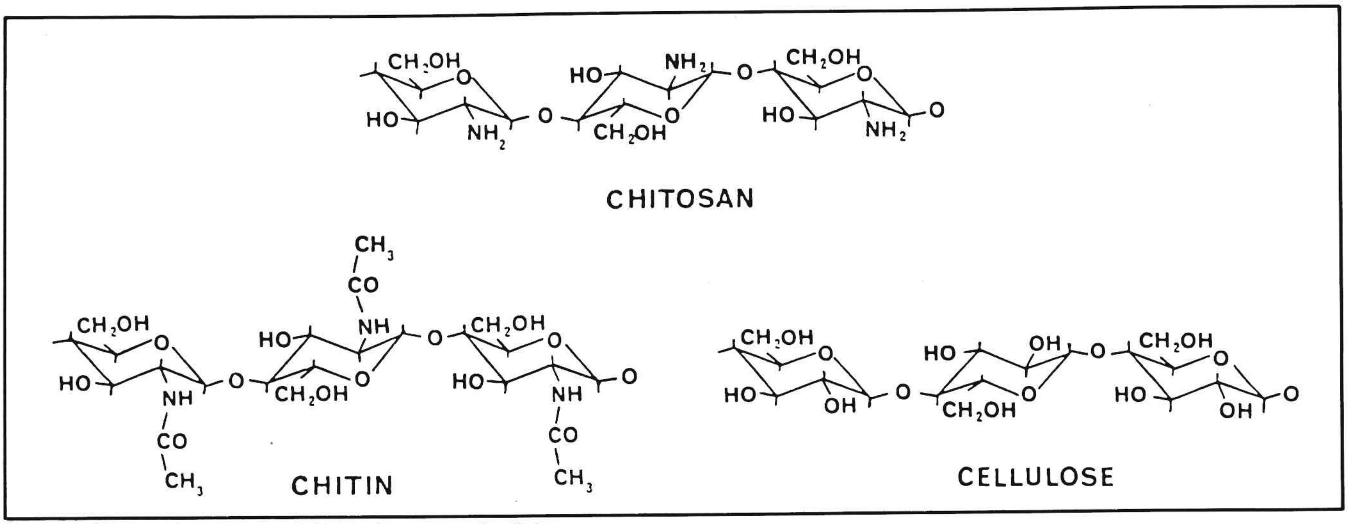

Figure 6. Chemical structures of chitin, chitosan and cellulose.

absorbent or filtration products respectively. Therefore, our attention has more recently focused on high value applications.

Some of the wet-laid nonwoven products made from microfungal mycelium superficially resemble leather in appearance. However, it was found that their dry and wet burst strengths were far too low for consideration as leather substitutes.

The most promising areas for commercial development relate to the novel cell wall chemistry of microfungal filaments, which is based on chitin or its partially deacetylated counterpart chitosan (Figure 6). The binding of toxic and heavy metal-ions by chitosan is well documented in the scientific press. This complexing ability is a direct consequence of the base strength of the primary amine group and is most effective for those metals that form complexes with ammonia, such as copper, silver and zinc. Thus, it was envisaged that filtration materials composed of microfungal filaments that had been alkali-treated to expose and partially deacetylate the chitinaceous region of the cell wall would have potential in the recovery of valuable metal-ions from various sources or removal of toxic metal-ions from industrial effluents.

Preliminary investigations at BTTG showed that the composite wet-laid papers produced from treated mycelia and conventional paper- or textile-fibres would indeed remove a range of metal-ions from solution and had reasonable tensile and burst strength properties in the wet state. However, the total metal-ion binding capacities of single-thickness microfungal papers are limited under constant flow conditions and when several sheets of microfungal paper are stacked together in an ion exchange column the concomitant reduction in flow rate becomes a limiting factor.

One solution to this problem is to produce a more open structure, for example, by impregnating a preformed polyester fleece with treated mycelium. In order to be fully commercially viable, the filters will also need to be regenerated in some way after they become saturated with metal-ions. This regeneration can be achieved by washing with a solution of dilute sulphuric acid which removes the metal-ions without affecting the absorption capacity of the filters.

Perhaps the most exciting application for microfungal nonwovens is in the field of wound management. Centuries-old folklore has pointed to the use of sea shells and mushrooms for the treatment of wounds. More recently, a body of evidence has built up over the past 20 years to suggest that chitin and chitosan have wound healing acceleration properties although the mechanism of action is still largely unknown. Indeed, the Japanese company Unitika is already marketing a nonwoven dressing based on chitin.

Commercial sources of chitin are derived from the exoskeletons of crustaceans as a byproduct of shellfish waste. However, the extracted chitin has to be dissolved in a suitable solvent and then extruded into a coagulation solution to produce the desired filamentous form.

Two British companies, Courtaulds and BritCair, have developed dressings based on another polysaccharide calcium alginate derived from brown seaweeds. These products have been developed, in particular, for the treatment of chronic wounds such as leg ulcers and bed sores which take many months to heal by conventional means and require daily dressing changes, thereby placing a considerable burden on hospital resources.

The market for new wound dressing materials is now expanding very rapidly and these products will certainly displace many of the traditional types of dressings which do not offer comparable clinical benefits, although they are often considerably more expensive to manufacture. Dressings based on microfungal filaments would have the competitive advantage that the chitin (or chitosan) is already in a fibrous form and only relatively cheap chemical treatments are required during processing.

It is envisaged that two sorts of dressing could be manufactured; an absorbent pad for the more serious wounds and a thin wet-laid membranous surface dressing. Of course, the two types of product can be combined together or used in conjunction with other materials to form a multi-layered structure.

Future developments

A joint venture was set up between BTTG and BNF Metals Technology Centre in April 1990 to develop a pilot-scale microfungal biosorption process for evaluation by participating companies. It is anticipated that this three-year project will provide the essential technological data for the development of a commercial process for the removal and recovery of metal-ions from aqueous industrial effluents.

Experimental microfungal dressings are currently being assessed using specialised tissue culture methods as models for the wound healing environment. Following the successful outcome of this research it is envisaged that one or more of the sponsoring organisations will be in a position to find the much more expensive developmental work leading up to and including clinical trials.

On a more speculative note, if fungal cells could be persuaded, using genetic engineering, to over-produce and retain a structural protein such as collagen then the possibility of producing a leather substitute from microfungal filaments might finally be realised. As to the ultimate textile material which can repair itself when it gets torn or damaged perhaps that should be the subject of our next research project. □