MODULE 3 HANDOUT 1

ARTICLE PERSPECTIVES

This handout contains excerpts from three articles:

- Frazier, Ian. Form and Fungus. *The New Yorker*, May 20, 2013.
- Holt, GA et al. Fungal Mycelium and Cotton Plant Materials in the Manufacture of Biodegradable Molded Packaging Material: Evaluation Study of Select Blends of Cotton Byproducts. (2012) *Journal of Biobased Materials and Bioegergy.* 6(4):431-439
- Bayer, Eben and McIntyre, Gavin. Methods for producting rapidly renewable chitinous material using fungal fruiting bodies and product made thereby. US 8001719 B2. 2011.

OUR LOCAL CORRESPONDENTS

FORM AND FUNGUS

Can mushrooms help us get rid of Styrofoam?

BY IAN FRAZIER

The makers of a mycelium-based packing material want to make plastics obsolete.

Gavin McIntyre, the co-inventor of a process that grows all-natural substitutes for plastic from the tissue of mushrooms, holds a pen or pencil in an unusual way. Gripping it between two fingers of his right hand, he moves his arm across the paper so that his wrist grazes the inscribed line; because of this, he uses pens with ink that doesn't smear. When he draws an explanatory diagram of the chitin molecule—chitin is the principal component of mycelium, the white, rootlike vegetative structure of fungi—he bends over his work, then looks up earnestly to see if his hearer has understood. The gesture makes him appear younger than his age, which is twenty-eight. He wears glasses and has straight black hair, dark eyes, and several piercings, with studs in his lip and ears.

The other co-inventor, Eben Bayer, won't be twenty-eight until June. Bayer is almost six-five, and often assumes the benign expression of a large and friendly older brother. His hair is brown, short, and spiky, his face is long, and his self-effacing manner hides the grand ambitions that people who come from small towns (Bayer grew up in South Royalton, in central Vermont) sometimes have. When he says, of the company that he and McIntyre founded, "We want to be the Dow or DuPont of this century," he is serious. He is their company's C.E.O., McIntyre its Chief Scientist. People with money and influence have bet that they will succeed.

Not long ago, McIntyre and Bayer and I sat and talked in the conference room of their thirty-two-thousand-square-foot factory, in Green Island, New York. They have been friends ever since they met in a design class at Rensselaer Polytechnic Institute, in nearby Troy, during the fall semester of their sophomore year, almost nine years ago. During our conversation, they leaned back and forth and sideways in the room's flexible ergonomic chairs, meanwhile tapping their iPhones to send and receive texts and e-mails to and from many people, perhaps including each other. McIntyre was wearing running shoes, jeans, a plaid shirt, and a forest-green pullover, and Bayer approximately the same. As they talked about their invention, they mentioned Burt Swersey, the teacher at R.P.I. who became their mentor and adviser.

I said that when I had talked to Swersey a few days before, I had told him of an invention of my own—a device to remove plastic bags from trees, which my friend Tim McClelland and I patented in 1996. Swersey had reacted to my small boast with scorn, saying, in so many words, that it was ridiculous to focus on annoyances like plastic bags in trees when humanity had far worse problems. McIntyre and Bayer both laughed. "Burt was always telling me my inventions sucked!" Bayer said. "And when I came up with an invention he liked he would only ask how I was going to make it better. If I came in with a cure for cancer, Burt would've said, 'O.K., but what about H.I.V.?' "

A real, serious problem that humanity has right now is Styrofoam. If the name is used accurately, it applies only to the foamed, extruded polystyrene product patented by Dow Chemical in 1944. Dow's Styrofoam is blue and serves mainly as a building insulation. More commonly, however, Styrofoam is the name people give to the white foamed polystyrene from which packing peanuts and coffee cups and fast-food clamshells are made. In widespread commercial use since the nineteen-fifties, Styrofoam is now everywhere. After Hurricane Sandy, its clumps and crumbs covered beaches along the Atlantic Coast like drifts of dirty snow.

Pieces of Styrofoam swirl in the trash gyre in the Pacific Ocean and litter the world's highways and accumulate in the digestive systems of animals and take up space in waste dumps; to reduce New York City's landfills, Mayor Bloomberg

PHOTOGRAPH BY BARTHOLOMEW COOKE

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would not be it. A dam has spanned the river from Green Island to Troy since the mid-eighteen-hundreds. In 1922, Henry Ford took advantage of the drop by building a generating station to provide power for a car-parts factory on Green Island. The factory is gone, but the power station is still operating.

The Mohawk River joins the Hudson in numerous branches above the dam, making the Hudson so wide that different parts of it reflect different parts of the sky. Most of the river flows over the dam in a white falls, but about six thousand cubic feet of it goes through the turbines every second. The whole generator building hums, and the flat, whorled water slides out the downstream side like a moving sidewalk. Ecovative likes to say that it gets its electricity only from renewable hydro power. The way power flies around the national grid, that might not always be true; in any case, a lot of Ecovative's electricity comes from the turbines at Green Island. Most electric power is generated and consumed almost simultaneously. The river with its wide-screen reflection of sky and clouds is keeping Ecovative's lights on in the moment that it flows past.

Whenever I visit the company, I like to stop first at an abandoned railroad bridge at the north end of Green Island. The branch of the Mohawk that the bridge spans has carved low bluffs from the island's four-hundred-million-year-old shale. The bluffs resemble stacks of very thin, reddish-black crêpes. All river confluences are glorious. Canoes full of Iroquois Indians travelled past here, and fur traders, and soldiers, and surveyors for the Erie Canal. The canal turned left near this point, followed the Mohawk's shale valley westward, tapped into the Great Lakes, and made the fortune of New York City. Here, as at all confluences, wildlife congregates. In the early morning, it's an amphitheatre of birdsong, while Canada geese add their usual commotion. So many crows show up in the evenings that they plague the town of Green Island, and the mayor has to scare them away with a blank pistol.

One Wednesday after a meditation here, I crossed the Hudson to Troy and stopped by Burt Swersey's Inventor's Studio class. Rensselaer, the oldest technological research university in the country, overlooks the Hudson from the east. The view from Swersey's classroom windows, however, was of a roof with some crookneck ventilator ducts that rotated back and forth. On the corkboard were pictures of Eben and Gavin, and news stories about them. They are heroes at R.P.I. The university's president, Dr. Shirley Ann Jackson, often mentions Eben and Gavin in her speeches. She says that they exemplify the best of R.P.I. and the goal that she champions: "Expedite Serendipity."

Swersey began the class by having the students tell what they were working on. A young R.O.T.C. cadet who was dressed in camo described his idea for a uniform with built-in tourniquets that would deploy automatically when a soldier was wounded. Other students' ideas had to do with helping the homeless, asthma sufferers, or people with Alzheimer's disease. A student from Kuwait suggested a public-area surveillance device that would detect people with incapacitating depression; then professionals could intervene and stop suicides. Swersey listened, offered a mixture of encouragement and skepticism, and told the students to talk to ordinary citizens to get feedback. "Getting out there and talking to people is absolutely critical," he said. "If you don't get out and talk to people, your grade is going to suffer."

Afterward, when most of the students had left, he was franker with the few who hung around to talk. "You're still not really getting it," he said, gloomily. "You're thinking in terms of ideas. I don't care about ideas. Find a *problem*, not an idea. Then solve the problem. Somebody had an idea to help stores in India so the food touched by untouchables didn't have to be thrown away. No—leapfrog that problem! Find the real problem! Forget about the thrown-away food—make it possible for the untouchables to be *touchable!* It's all about empathy! Right now you're attempting small things. I want something fantastic. Not something good, not even something great—something fantastic. Find a problem so outrageous in its scope that it's probably impossible. Start on it right away—next class. You have only seven more weeks in the semester."

A young woman named Paula, whose project involved thermo-engineering with plots of solar-heated sand, had been arguing with Swersey, but at this she gave in. "O.K., Burt," she said. "Before the next class, I will come up with something impossible." ♦

IMAGINED INVENTIONS

LEANING IN

BY MINDY KALING

One of the great perks of my job is that I regularly get to kiss men—often married men—with zero repercussions for anyone involved. Obviously, I am playing a character, Dr. Mindy Lahiri, so technically I should not be enjoying it as Mindy Kaling. But, honestly, who is going to know if I slip in and out of character in the heat of the moment? That's between me and my conscience.

Enduring, committed relationships are wonderful and sacred things. I hope to enter into a really good one at some point. However, kissing new people is also one of the great joys in life, and I believe the two should be able to coexist peacefully. Why should saying "I do" necessarily mean "I will not kiss another human for the rest of my life"?

Before people start thinking I'm some Hollywood weirdo advocating open marriage, let me quickly say, I'm just talking about kissing here. The fact of the matter is, marriage is a serious business and kissing is not. Kissing in and of itself can't create offspring or cause life-threatening disease. Just because I want to kiss someone doesn't mean I want to love that person, share a bed with him, remind him to take his Lipitor, tell him not to use so much salt, or share one AOL e-mail account.

The problem is, kissing is no longer appreciated as a satisfying end in itself, as an inviting pair of lips and, possibly, a tongue, to interact with for a delightful moment. No. Kissing has now been cheapened into the nominal gateway gesture to sex. Kissing is to sexual intercourse as the phrase "Can I talk to you for a second?" is to a full-blown screaming fight.

Let me paint a pretty typical picture of the last person you made

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US008001719B2

(12) **United States Patent**
Bayer et al.

(10) **Patent No.: US 8,001,719 B2**
(45) **Date of Patent: Aug. 23, 2011**

(54) **METHOD FOR PRODUCING RAPIDLY RENEWABLE CHITINOUS MATERIAL USING FUNGAL FRUITING BODIES AND PRODUCT MADE THEREBY**

(75) Inventors: **Eben Bayer**, Troy, NY (US); **Gavin McIntyre**, Green Island, NY (US)

(73) Assignee: **Ecovative Design, LLC**, Green Island, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 19 days.

(21) Appl. No.: **12/456,408**

(22) Filed: **Jun. 16, 2009**

(65) **Prior Publication Data**

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Related U.S. Application Data

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(51) **Int. Cl.**
A01G 1/04 (2006.01)

(52) **U.S. Cl.** **47/1.1**

(58) **Field of Classification Search** 47/1.1; 435/254.1
See application file for complete search history.

(56) **References Cited**

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Primary Examiner — Francis T Palo
(74) *Attorney, Agent, or Firm* — Francis C. Hand; Carella, Byrne, Cecchi

(57) **ABSTRACT**

The method of growing a fungal fruiting body requires exposing a mycelium of a desired organism type to environmental conditions sufficient to induce fruiting of fungal primordium in the organism type followed by enclosing the fungal primordium within a mold of a designated shape representing a near net shape volume of a desired final product. The fungal primordium is allowed to grow and fill the mold to form a mass of fungal tissue equivalent in shape to the designated shape of the mold after which the mass of fungal tissue is removed from the mold and dried.

11 Claims, 25 Drawing Sheets

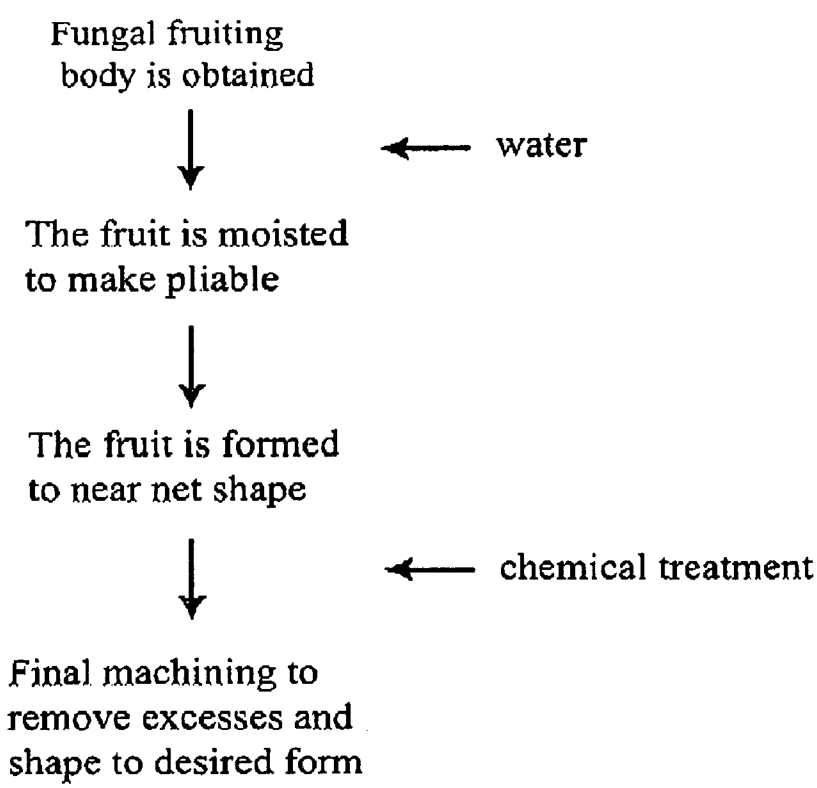
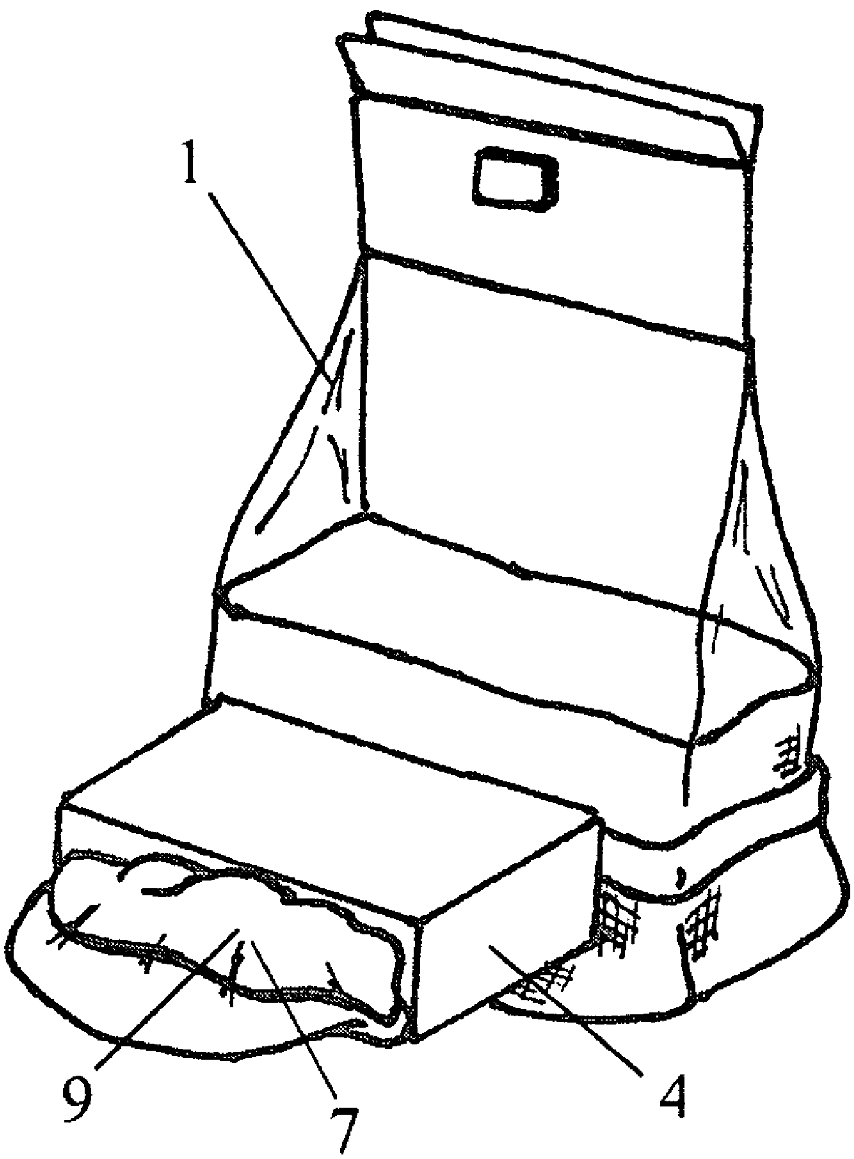


Figure 9



METHOD FOR PRODUCING RAPIDLY RENEWABLE CHITINOUS MATERIAL USING FUNGAL FRUITING BODIES AND PRODUCT MADE THEREBY

This invention claims the benefit of Provisional Patent Application No. 61/132,161, filed Jun. 16, 2008, the contents of which is incorporated by reference herein.

This invention relates to a method for producing grown materials and to the products made by the method. More particularly, this invention relates to methods for producing organic constructions. Still more particularly, this invention relates to methods for producing organic structural cores, wood like materials, and other structural materials.

BACKGROUND OF THE INVENTION

Materials are produced today using a range of processes ranging from time intensive outdoor growth and harvesting to energy intensive factory centric production. As demand for raw goods and materials rise, the associated cost of such materials rises. This places greater pressure on limited raw materials, such as minerals, ores, and fossil fuels, as well as on typical grown materials, such as trees, plants, and animals. Additionally, the production of many homogenous materials and composites produces significant environmental downsides in the form of pollution, energy consumption, and a long post use lifespan.

Conventional materials such as expanded petroleum based foams are not biodegradable and require significant energy inputs to produce in the form of manufacturing equipment, heat and raw energy. Conventionally grown materials, such as trees, crops, and fibrous plants, require sunlight, fertilizers and large tracts of farmable land.

Finally, all of these production processes have associated waste streams, whether they are agriculturally or synthetically based.

Fungi are some of the fastest growing organisms known, with some types, such as *Neospora* sp., growing up to 40 μm/minute. Fungi exhibit excellent bioefficiency, of up to 80%, and are adept at converting raw inputs into a range of components and compositions. Fungi are composed primarily of a cell wall that is constantly being extended at the apex of the hyphae. Unlike the cell wall of a plant, which is composed primarily of cellulose, or the structural component of an animal cell, which relies on collagen, the structural oligosaccharides of the cell wall of fungi rely primarily on chitin and Beta Glucan. Chitin is a strong, hard substance, also found in the exoskeletons of arthropods. Chitin is already used within multiple industries as a purified substance. These uses include: water purification, food additives for stabilization, binders in fabrics and adhesives, surgical thread, and medicinal applications.

Given the rapid growth times of fungi, its hard and strong cellular wall, its high level of bioeffeciency, its ability to utilize multiple nutrients and resource sources, and, in the filamentous types, its rapid extension and exploration of a substrate, materials and composites produced through the growth of fungi can be made more efficiently, cost effectively, and faster than through other growth processes and can also be made more efficiently and cost effectively than many synthetic and organic processes.

Numerous patents and scientific procedures exists for the culturing of fungi for food production, and a few patents detail production methods for fungi with the intent of using its cellular structure for something other than food production. For instance U.S. Pat. No. 5,854,056 discloses a process for

the production of "fungal pulp", a raw material that can be used in the production of paper products and textiles.

Accordingly, it is an object of the invention to provide a method for the culturing and fruiting of filamentous fungi specifically for the production of materials and composites composed in part, or entirely of, hyphae and its aggregative form, mycelia and mycelium, when such hyphae are formed into a fruiting body.

It is another object of the invention to provide a material made in part or in whole of cultured fungi.

It is another object of the invention to provide an enclosure for growing composites and materials comprised of fungi fruiting bodies.

It is another object of the invention to provide a mixture of particles for use in the growing of filamentous fungi to produce a homogenous or heterogeneous material.

Briefly, the invention provides a method for producing grown materials and, in particular, provides a method of using the growth of an organism to produce materials and composites.

In accordance with the invention, a fungus is cultured for the production of a material using the vegetative phase of the fungus, mycelium. This fungus is typically a Basidiomycete.

Basidiomycetes are a phylum of fungi that create a fruiting body (mushroom) to produce spores as a method of sexual reproduction. These fruiting bodies are diverse and take specific forms based on environmental, chemical, and physical stimuli from the substrata/environment from which the fungus is grown.

In this disclosure we describe a series of processes that allow fruiting bodies to be rapidly grown into a low density, chitinous material that can replace balsa, bass, other woods, and also many foamed plastics.

Growing a tree requires 7 to 8 years of favorable outdoor environmental conditions, while our fungal material can be grown in as little as 3 weeks from initial substrate inoculation to final product[1]. The fruiting body, from which the structural material is derived, can be grown to near net shape by encapsulating the fungal primordium in an enclosure of the desired form which controls the microclimate. By growing the fungal fruiting body to a desired shape only minor post processing is required, reducing waste. Controlling the microclimate around the fruiting body allows precise modification of the fruiting bodies morphology including pileus[2] to stipe[3] length, pileus and stipe shape, diameter, thickness, density, surface finish, fiber orientation, color, length, and width. Additionally, fruiting bodies, either formed using an enclosure or by other means, can be post-processed to desired material dimensions including shapes such as blocks, cylinders, sheets, spheres, and other combinations of three dimensional solids. Manufacturing processes that may be employed during post processing include, but are not limited to, machining, forming, pressing, drying, sanding, cutting, milling, turning, burning, heating, drying, cooling, water jet cutting and drilling.

[1] Regarding *G. lucidum*. Growth of Fruitbody Formation on *G. lucidum* on Media Supplemented with Vanadium, Selenium, and Germanium. Tham, L; et al. 1998

[2] A pileus is the mushroom cap that contains either spore tubes or gills, pl. plieuses

[3] A stipe is the mushroom stalk

Although the majority of Basidiomycetes and some macro Ascomycetes are applicable for creating structural materials utilizing fungi tissue, the order of Polyporales was selected particularly for its production of structural spore tubes, pilei, are enclosed within a single mold, and proper environmental conditions are observed, the resulting stipe or pileus tissue will fuse into a single monolithic fruiting body, a characteristic undesirable in conventional mushroom production. Finally, the act of growing a fruiting body into a near net shape other than that typically taken on by a mushroom is at odds with the goals of conventional cultivation which prize and benchmark against the natural morphological structure of fruiting bodies as seen in nature. In fact, defective fruiting bodies are often identified by their non-conformity to this morphology.

Additionally, the static embodiments of this material, typically used as a self supporting structural material, is at odds with the conventional use of fungal tissue as a food source for humans or animals. Additionally, the static embodiment of fungal tissue resulting from any of the processes described above has characteristics different from those found in conventionally grown mushrooms. These characteristics include a distinct shape, controlled by the mold in which the fruiting body was grown. These characteristics also include fungal tissue configurations which are not seen in natural growth, including elongated stipes, and pilei formed into non-optimal spore producing configurations. These characteristics also include fungal tissue configurations which would not typically be seen in conventional cultivation or nature, such as thigmotropic response along a significant portion of fungal fruiting bodies surface area. The surfaces of fungal fruiting bodies may also differ from those found in nature, becoming smoother and more homogenous when in contact with the mold.

Our method differs from other methods focussed on harnessing mycelia products, such as U.S. Pat. No. 5,854,056, because it leverages the fungi's ability to self assemble its modular cells into complex self supporting 3-D structure. This results in self supporting mycelia structures with have a controlled 3-D shape. For instance, in the '056 patent, mycelia is cultured in liquid vats and grown into a thin sheet. In this embodiment, the mycelia partially takes on the dimensions of the trough of which it is grown in, but only in a 2-D space, as the thickness of the mycelia sheet is not controlled and nominally thin enough to be referred to as a sheet and not a 3-D solid. Additionally, while the '056 patent does make reference to the mycelia balls intermeshing when growing into a sheet, the final product is not treated as a self supporting, rather being referred to, and used as, pulp. In our embodiments, this mycelia tissue is allowed to self assemble under the environmental conditions which produce dense strong tissue, such as the tissue type which is found in a fruiting bodies stipe in nature. Furthermore, the mycelia tissue contemplated in our embodiments is formed into a 3-d structure with dimensions controlled along each of the shapes surfaces. Finally, in our process the final product is a self supporting 3-d structure, in the patent '056, the fungal mass must be ground, combined with paper pulp, and then pressed, to result in a self supporting structure.

These and other objects and advantages of the invention will become more apparent taken in conjunction with the accompanying drawings wherein:

FIG. **1** illustrates a post processing flow diagram in accordance with the invention;

FIG. **2** illustrates a growing to form flow diagram in accordance with the invention;

FIG. **3** shows a perspective view of a simplified apparatus for producing formed fungal fruiting bodies in accordance with the invention;

FIG. **4** shows the apparatus from FIG. **3** after several days of fungal fruiting body growth;

FIG. **5** shows the apparatus from FIG. **3** with a growth enclosure attached.

FIG. **6** shows the flexible incubation bag of FIG. **5** after the attachment of an enclosure with a stipe and pileus formed into the enclosure shape;

FIG. **7** shows a perspective view of a simplified apparatus for producing formed fungal fruiting bodies in accordance with the invention;

FIG. **8** shows the apparatus from FIG. **7** after several days of fungal fruiting body growth;

FIG. **9** shows the flexible incubation bag of FIG. **7** with a stipe and pileus formed into the enclosure shape;

FIG. **10** shows a perspective view of a simplified apparatus for producing formed fungal fruiting bodies in accordance with the invention;

FIG. **11** shows the flexible incubation bag of FIG. **10** after additional fruiting body growth;

FIG. **12** shows the fruiting body growth of FIG. **10** taking on the form of the enclosure

FIG. **13** shows the finished part produced from the enclosure shown in FIG. **12**.

FIG. **14** illustrates a laminated structure in accordance with the invention.

FIG. **15** shows a perspective view of a simplified apparatus for producing formed fungal fruiting bodies in accordance with the invention;

FIG. **16** shows the flexible incubation bag including an enclosure with mesh.

FIG. **17** illustrates a section of material formed from the fruiting body of FIG. **16** including an embedded mesh.

FIG. **18** shows a flexible incubation bag with multiple punctures for processing multiple fruiting bodies in accordance with the invention;

FIG. **19** shows the flexible incubation bag of FIG. **18** after the attachment of a enclosure with multiple orifices;

FIG. **20** shows the flexible incubation bag of FIG. **18** after additional days of fruiting body growth;

FIG. **21** shows the finished part created from the enclosure shown in FIG. **19** and FIG. **20**.

FIG. **22** shows a ply board made from chipped fungal fruit in accordance with the invention.

FIG. **23** shows a section of material ready for processing.

FIG. **24** shows the block of FIG. **23** fully moistened and pulled over a rod.

FIG. **25** shows the block of FIG. **24** fully dried and maintaining the shape conferred by the rod.

EXAMPLE 1

Grown Fruiting Body

Pleurotus Ostreatus was cultured on a rye grain substrate for 21 days. This substrate was comprised of 75% rye grain and 24% perlite by dry weight. The substrate was buffered with 1% gypsum by weight and contained 63% water by weight. Rye Grain was obtained from The Honest Weight food CO-OP in Albany, N.Y. Perlite and gypsum were obtained from The Home Depot, located in Latham, N.Y. City water, from the municipality of Troy, N.Y., with a pH of 7, was used to wet the material. The grain, perlite, gypsum, and water were combined together in a 1.5 gallon opaque autoclavable bag obtained from Fungi Perfecti and manually shook for 3 minutes to fully mix the materials. They were than autoclaved for 1 hour at 15 PSI and allowed 24 hours to cool to room temperature. These bags were then inoculated using a liquid culture of *Pleurotus ostreatus* cells. The liquid culture of *Pleurotus ostreatus* cells was contained in a 4 L Erlenm-

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Fungal Mycelium and Cotton Plant Materials in the Manufacture of Biodegradable Molded Packaging Material: Evaluation Study of Select Blends of Cotton Byproducts

G. A. Holt[1,*], G. McIntyre[2], D. Flagg[2], E. Bayer[2], J. D. Wanjura[1], and M. G. Pelletier[1]

[1] *USDA-ARS Cotton Production and Processing Research Unit 1604 E. FM 1294, Lubbock, TX 79403, USA*
[2] *Ecovative Design, LLC, 60 Cohoes Avenue, Green Island, NY 12183, USA*

RESEARCH ARTICLE

Since polystyrene is non-biodegradable, a biodegradable material that is eco-friendly is being sought as a substitute for packaging and insulation board consumers. One such process, developed by Ecovative Design, LLC, involves growing fungal species on agricultural biomass to produce an eco-friendly packaging product (EcoCradle™) and insulation panels (Greensulate™). The objective of this research was to develop and evaluate six blends of processed cotton plant biomass (CPB) materials as a substrate for colonization of selected fungi in the manufacture of molded packaging material. The blends were comprised of processed CPB, cotton seed hulls, starch, and gypsum. The four ingredients were the same mix percentage for all six blends with the particle size of the CPM being the only difference. CPB particles sizes ranged from 0.1 to 51 mm. Tests were conducted to evaluate the physical and mechanical properties of the six CPB blends. Test results revealed blends that met or exceeded like characteristics of extruded polystyrene foam.

Keywords: Composite, Cotton, Mycelium, Biobased, Biodegradable.

1. INTRODUCTION

Polystyrene is a hydrocarbon based material typically used in the manufacture of packaging materials. Marketed under the name Styrofoam™, this lightweight material is hydrophobic, resistant to photolysis, and is not subject to decomposition or decay.[1] These characteristics are attractive to shippers and the packaging industry, but they create problems with respect to recycling, reuse, and landfill operation.[2] Recent scientific investigation resulted in development of an economically viable, environmentally friendly replacement for polystyrene packaging materials. The packaging material evaluated in our study is a composite containing selected agricultural residues and a specific fungus.

Annually renewable crops and their agricultural residues have been researched extensively as materials that could potentially enhance the properties of composite products made from fossil fuel based derivatives that are more resistant to biodegradation.[3–6] In addition to the crops and agricultural residues, fungi and/or their constituents have been studied and used to manufacture environmentally friendly products.[7–10] The combination of agricultural residues and fungi have been evaluated for fungal cultivation[11–15] and improving bonding properties of agricultural fibers in the manufacture of composites.[16,17] However, a method for producing a composite comprised of agricultural residues and fungi was not found in the literature.

Bayer et al.[18] and Bayer and McIntyre[19] developed processes that involve growing fungal species on agricultural residues, such as cotton plant material, to produce an environmentally-friendly packaging material. The objective of the present study was to develop six blends of specifically processed cotton plant material for use with the Bayer et al.[18] and Bayer and McIntyre[19] processes. Each of the six blends was used to produce a packaging material that was subjected to standard test methods for compressive strength,[20] flexural strength,[21] modulus of elasticity,[21] density,[22] dimensional stability,[22] accelerated aging,[23] water absorption,[24] cone calorimetry,[25] and thermal conductivity.[26] The cotton plant material used in this study was a byproduct of typical mechanical harvesting and ginning practices in the United States which generate approximately 2.5 Mg of cotton byproducts across the U.S. cotton belt each year.[27]

*Author to whom correspondence should be addressed.
Email: greg.holt@ars.usda.gov

 1556-6560/2012/6/431/009 doi:10.1166/jbmb.2012.1241

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3. RESULTS AND DISCUSSION

3.1. Physical Properties

Figure 8 shows a comparison of the dimensional stability (surface area contraction) of the treatments after drying. Blends inoculated with the grain-based substrate showed less surface area contraction than did blends inoculated with the liquid-based substrate. Grain 3 (Blend 3, grain-based inoculum) had the smallest measured surface area contraction (0.64%), whereas Liquid 5 (Blend 5, liquid-based inoculum) exhibited the greatest measured surface area contraction (2.4%). Grain 3, 4, 5, and Liquid 6 were similar in the percent contraction and significantly lower than Grain 2, Liquid 1, 2, 3, 4, and 5.

The importance of dimensional stability is related to tool design. The larger the percent contraction the more oversized the tool needs to be for the finished product to be within desired specifications. Another factor influencing tool design is contraction variability. The more variable a blend/inoculum combination is, the more difficult it is to produce parts that are consistently within dimensional tolerances of customer specifications. All treatments had similar standard mean errors associate with percent contraction (0.093 to 0.108), so the means are a reliable indicator of the contraction expected when designing tools for a given treatment.

The flexure strength (FS), elastic modulus (EM), and compressive strength (CS) in Table II are normalized to a standard density of 32.04 kg/m^3 since this is the density of the polystyrene packaging the EcoCradle material can replace in the market. The density of the treatments ranged from 66.5 kg/m^3 to 224 kg/m^3. The density for grain treatments was higher than for the liquid treatments due to the greater mass of the grain-based inoculum versus the liquid-based inoculum. The density adjusted values for FS show Grain 1 and Grain 6 with the highest values at 26 kPa and Liquid 2 with the lowest at 7 kPa. The EM was significantly higher for Liquid 5 (674 kPa) than all other treatments with Liquid 2 having the lowest, 123 kPa. Compressive strength was significantly higher for Liquid 3 (72 kPa) than for all other treatments with Liquid 4 having the lowest CS at 1.1 kPa.

Sample degradation associated with FS, EM, and CS resulting from accelerated aging testing is shown in the second column of Table II. The percent degradation data was calculated according to the equation in the standard:[23]

$$\text{Degradation Percentage} = (\text{Conditioned test value/as received test value}) * 100$$

Therefore, values closer to the base line (100%) exhibit less degradation than samples with values further from the baseline. FS degradation for Grain 5, 1, 6, and Liquid 3 exhibited little degradation from aging. Liquid 5's FS was reduced almost in half as a result of aging whereas the FS of Grain 3 and Liquid 2 exhibited increased stiffness due to aging. EM for Grain 6 had the largest change in percent degradation of 318.6%. Liquid 5 had the largest reduction in EM at 43.6%. The treatments that had the largest percent CS degradation were Liquid 5 (250.1%) and Liquid 3 (6.8%). The CS degradation was least for Grain 4 (92%) and Grain 1 (110%). Overall, Grain 1 had the most consistent performance, by exhibiting some of the lowest degradation values for FS, EM, and CS compared to all other treatments.

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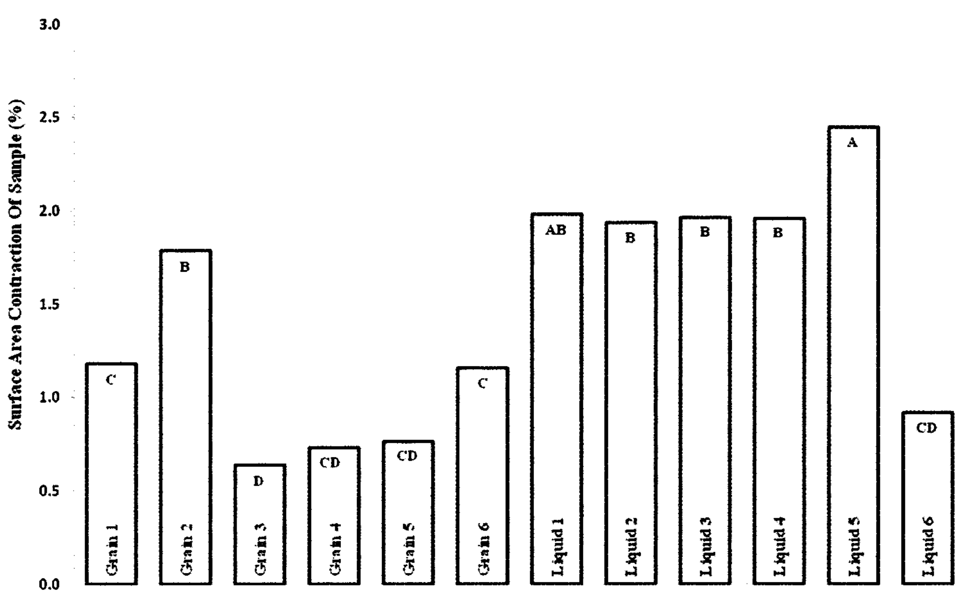

Fig. 8. Average surface area contraction (%) or shrinkage of the sample pieces made from each treatment after oven drying. Bars with the same letters are not significantly different at the 0.05 level of significance.

primarily to the added weight of the grain. The densities were higher than desired (32.04 kg/m^3) due in large part to the inclusion of cotton plant particles less than 2 mm. In future studies, cotton plant material having a diameter less than 2 mm will not be used. No single treatment outperformed the other treatments in all categories evaluated. Most of the treatments performed similarly to each other for the response variables measured. In regards to percent degradation associated with accelerated aging testing, Grain 1 was most consistent in maintaining flexural and compressive strength and elastic modulus.

Overall, the use of cotton-based fungal mycelium packaging material is a viable alternative to polystyrene packaging. As refinements in processing and biomass blend development continue, the physical and mechanical properties of the product should improve. Improved physical characteristics will cause agricultural residue-based fungal composites to be suitable for numerous applications that presently use fossil-fuel based materials.

Abbreviations

CGB: Cotton Gin Byproducts

Disclaimer

Mention of product or trade names does not constitute an endorsement by the USDA-ARS over other comparable products. Products or trade names are listed for reference only. USDA is an equal opportunity provider and employer.

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