Critical Analysis of Materials Options

Substitutes for Polystyrene Foam Packaging

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**Introduction** (Isaiah Stevens)

According to *The Real Cost of Styrofoam*, a report presented to St. Louis Earth Day, our landfills are comprised of 25% to 35% polystyrene foam, commonly referred to as Styrofoam, by volume [1]. Styrofoam is often used in disposable cups, food packaging, and packaging materials. While the cost and ease of manufacturing makes the use of Styrofoam highly desirable, the material itself can pose threats to both the environment and human health. Our primary focus and goal is to find acceptable substitutes for polystyrene foam used in packaging materials that is both better for the environment and less toxic towards human health. We also hope that the substitutes will compete with the properties of Styrofoam packaging, such as its light weight and protective ability. We propose that mushroom packaging, made from mycelium and hemp hurd [3], and porous clay-organic composites [4] would be a sustainable replacement for Styrofoam in packaging materials.

**Environmental Regulations and Impacts** (Isaiah Stevens)

One of the primary reasons we chose to find a substitute for Styrofoam in packaging materials was because of the impact that Styrofoam has on the environment. As mentioned in our introduction, a significant percentage of our waste consists of Styrofoam products. According to *The Real Cost of Styrofoam* “80% of Styrofoam ends up in landfills, and much of the remaining 20% in waterways (as per U.S. Environmental Protection Agency: 3 million tons of polystyrene produced in the U.S per year; 2.3 million tons end up in landfills, with much of the remainder finding its way into waterways)” [1]. Not only is an obscene amount of Styrofoam from to waste every year, the cost to recycle the material is very high. Primarily because of its lightweight property, Styrofoam costs $3000 dollars per ton to recycle [1]. Because of the high cost, Styrofoam is rarely recycled. One of the reasons that this is a problem is because it can take up to 500 years for Styrofoam to decompose [1].

Mushroom packaging is one potential substitute for polystyrene foam for use in packaging materials. Figure 1 shows how manufacturers make and mold the mushroom packaging. The packaging is made from only two ingredients: mycelium and hemp hurd. “Mycelium is the root-like structures that extend out of fungi and underneath the outer layer of the cap. However, the product called mycelium is a bio-engineered form of [hyphae](https://biologydictionary.net/hyphae-vs-mycelium/) that is made from agricultural waste mixed with these root-like structures as binding agents” [2]. Hemp hurd is the agricultural waste from hemp stalk. Both are organic materials. Unlike Styrofoam, mushroom packaging decomposes in a reasonable amount of time. The home-compost time of mushroom is 45 days, and the marine-compost time is 180 days [3]. This is a significant difference from Styrofoam’s compost time of 500 years. This makes mushroom packaging a better substitute for Styrofoam.

Similar to mushroom packaging, porous clay-organic composites are made from organic materials. According to an article published in the journal *Elsevier*, “Porous clay-organic composites have been prepared by lyophylization of mixtures of clay and organic sols. They are shown to have properties applicable for packing and for use as insulating buffer material. The organics which have been used are all naturally reproduceable in the biosphere” [4]. The natural reproducibility of the materials in porous clay-organic composites makes it a more environmentally sustainable option for packaging materials than Styrofoam. Although we could not find a decomposition time for porous clay-organic composites, their organic nature would likely mean a more environmentally conscious disposal.

We chose to look at organic-based packaging materials rather than bioplastics because bioplastics can have long decomposition times. According to an article published at the Yale School of Environment, “If bioplastics end up in landfills, they can last for centuries and release methane, a potent greenhouse gas” [5]. As we have shown, organic-based packaging materials are much more friendly towards the environment.

**Standards** (Kyla Woodruff)

Material standards are necessary to compare various materials to one another and decide which is the better fit for various circumstances. The ASTM, The American Society of Testing and Materials, has six different standards listed that can be assessed and used to compare. These six standards are test method, specification, classification, practice, guide, and terminology [6]. It is important to have these standards set for engineers, so that materials can be fully assessed for manufacturing purposes and for safety purposes while the materials are being evaluated and used.

When researching various replacement materials for the Styrofoam packing peanuts, the physical properties of Styrofoam must be organized and sorted into its pros and cons, so that it is easier to figure out what properties are important to keep in the new replacement materials and which are not. Styrofoam is harmful to the environment but supplies significant support when shipping items and is very lightweight. The Styrofoam standards that are being used pertain to the packing peanuts made up of expanded polystyrene (EPS). Expanded Polystyrene is not a flame retardant and is not a biodegradable material. This version of polystyrene has a density of two pounds per cubic foot, making it very lightweight [8]. The flexural strength, also known as modulus of rupture, of expanded polystyrene is fifty-eight psi and the stress of the foam at 10% compression is 30 psi [7]. These standards provide that the Styrofoam is extremely lightweight, yet is highly compressible under low amounts of stress.Table

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The first material that is being considered as a replacement to typical expanded polystyrene in packaging is a type of mushroom called Mycelium. Mycelium is being considered as a replacement due to its great environmental factors, light weight, simplicity to grow and manufacture, as well as the materials compressibility. According to Mycelium’s standards reference sheet [9], the density of Mycelium in packaging form is 7.5 pounds per cubic foot. This is significantly denser than the expanded polystyrene, however this material’s compressive strength is better with 18 psi at 10% compression. Since Mycelium is fully biodegradable, it has a compatibility of only 30 days before it begins breaking down. For long term packaging, this might not be fully ideal, however for quick shipments and orders this is a great alternative.

Diagram, engineering drawing

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The second material considered as a replacement for expanded polystyrene packaging is porous clay-organic composites. Similarly, to Mycelium, this material is fully biodegradable and naturally made. This material can also be altered to be porous and lightweight due to the needs of the material and the standards that it may need to meet. The larger the load and compression percentage is on the porous clay composite, the average will slightly decrease, making it less and less compressible in relation to a higher load. However, this Agar composite is engineered to have slight decrease in pore size for an agar-based clay compared to a normal clay, making it withstand more compression in a 3:7 ratio. When looking at the compressive strength vs. composition graph below, a porous clay composite with low amount of agar content in weight percent will have a much lower compressive strength than a clay composite with a higher agar ratio present [10]. The density of these porous clay composites is highly dependent on the composition of the agar content of the packaging and how compressible the user wants the material to be when shipping. However, a comparable clay aerogel composite with a high porous amount has a density of about 1.00 gram per cubic centimeter [11]. Although these porous clay composites may be slightly more difficult to manufacture on a large scale and have a capability of being heavier, they are significantly stronger than the original expanded polystyrene and mycelium [12].

**Material Toxicity** (Michael O’Brien)

Toxicity of materials is an important topic that must be addressed and researched when considering new materials for packaging. This topic may often get forgotten or overlooked when looking into new materials, but in material applications for packaging it is especially important to pay attention to toxicity as packing materials can easily fall into the hands of children and create some unanticipated situations that were not intended. Thus, we must be prepared for these situations by informing the user and considering any and all dangers of the material, or at very least analyze the possible impacts or toxic situations in which the materials chosen could affect or significantly impact the user in matters of safety. These may include sickness, death, or other hazardous situations in order to advise and inform the user for their safety and knowledge for unanticipated situations. Therefore, they will know the severity of possible occurrences and know how the situations may need to be addressed depending on the materials’ effects and toxicity. Fortunately, the chosen materials, which are mycelium and porous clay composites, exhibit natural properties contrary to common packing materials such as Styrofoam or various plastics.

For the mycelium application in packaging, minimal toxicity is present to users because the material is made fully from grown mushrooms. Thus, this material is not toxic to the environment as it is biodegradable, breaking down in 30 days [2]. If this product is accidentally consumed, there should be no major health impacts unless consumed in large amounts, then mild sickness may occur. Eating this product is still not an intended use and is not advised. The toxicity of packaging is important to consider as well, as possible harmful effects to workers and the environment must be kept in mind when fully analyzing a material and its applications. When mycelium is made, the fungal spores feed on woodchips, corn husks, or hemp [2]. These materials are all natural and ecofriendly. The mycelium is grown in a plastic mold as well, which is recyclable. Thus, there exists no considerable toxic effects from the production of mycelium.

For the porous clay organic composite applications, creating a packing material requires a ratio of many organic resources. These resources include agar, starch, gelatin, sodium alginate and carboxymethyl cellulose [4]. These all come from clay, seaweed, or other natural composites in the ground. Because these are all natural resources from the top of the earth’s crust, they can be returned to the environment with no harm after use [4]. Thus, the toxicity to the environment is non-existent. The toxicity to humans is only present if accidentally eaten. This will provide the same dangers as eating clay. Thus, if a small amount is consumed, no severe effects will occur. In the production of this organic composite material, the organic resources are mixed only with water in a process to create and control the pores [4]. Thus, no toxicity is involved in the making of these composites.

In terms of the common packing material, Styrofoam, there are many toxic impacts and possible dangers in the production as well as the unintentional uses for it. Firstly, processes during production “have been shown to pollute the air and create large amounts of liquid and solid waste that end up in streams and landfills” [1]. Thus, Styrofoam yields a big negative effect on the environment from production. In addition, Styrofoam is not made with biodegradable materials, so disposal after use causes solid pollution to the environment. Also, when Styrofoam is heated, toxic chemicals are created that are harmful to humas [13]. Additionally, if Styrofoam is burned, which may occur in attempt for disposal, toxic fumes are released that are dangerous if inhaled. Another harmful effect may occur if Styrofoam is consumed. Although Styrofoam is not intended to be eaten, consuming a small amount of Styrofoam has shown to not be dangerous. However, if larger amounts are consumed, this could cause greater health problems, as it won’t pass through the digestive system as easily because it doesn’t get broken down [13]. Additionally, this could cause chocking and other issues as Styrofoam may get stuck in the esophagus [13]. Thus, this packing material can cause much unintended harm in a variety of scenarios.

It has been shown that toxicity in production as well as effects on humanity is remarkably decreased when considering either mycelium or porous clay composites in place of polystyrene foam in packaging applications. Because the mycelium and porous organic clay composites exhibit identical properties of Styrofoam as well as the added ability to be returned to the environment after use, they both provide a great alternative, as well as display huge advantages over the well-known Styrofoam.

**Conclusion (**Kyle Johnson)

As the chief materials engineer on this new development project to find substitutes for polystyrene foam packaging, my team and I, for the reasons given, believe a good alternative would be mushroom packaging made from mycelium and hemp hurd [3], and porous clay-organic composites [4]. These aforementioned materials would be practical, environmentally friendly, adhere to materials standards described by The American Society of Testing and Materials, and have very low toxicity.

Being made from organic materials, both mushroom packaging and the porous-clay organic composites decompose much faster than Styrofoam does. Compared to the five hundred years it takes for Styrofoam to decompose, it only takes the mycelium and hemp herd material 45 days in a home-compost and 180 days in a marine-compost [3]. Organic-based packaging materials were focused by our team over bioplastics due to bioplastic’s long decomposition time and its tendency to release methane as it does so [5]. Not only is this a lot of Styrofoam in our landfills, it is a lot of non organic material that is inevitably going to be in places it shouldn’t, such as our oceans and other wildlife habitats. Recycling Styrofoam is rare due to its high costs, so it is important for us to find an alternative that is easier on the environment when disposed of and these materials fit that requirement.

When comparing the material standards provided by The American Society of Testing and Materials: these material standards being test method, specification, classification, practice, guide, and terminology, we found both alternative materials to be superior to Styrofoam in many ways [6]. Compared to Styrofoam, the mycelium and hemp herd based mushroom packaging has some similarities such as its lightweight factor, but it stands out when it comes to environmentally friendly nature and its compressive strength [9]. Mycelium does begin to break down within 30 days however, which could cause issues for long term packaging, but it is still a great alternative for short term. When it comes to the porous clay-organic material, other than its ability to be fully biodegradable, naturally made, and lightweight, its biggest strength comes in its property to be significantly stronger than both the original expanded polystyrene and the mycelium based mushroom packaging [12]. This second alternative also has the ability to be altered when it's needed to be more porous or lightweight.

As far as the toxicity of these materials goes, they have many properties that lead to less of the common problems Styrofoam tends to have in this area. With mycelium being made completely from mushrooms, it is not toxic to the environment or will take a long time to decompose [2].. And unless large amounts are ingested, this natural product will not cause any problems. This is a huge benefit considering how easy it is for small children to get their hands on styrofoam. The porous clay-organic composite material is also made of all natural resources and provides no harm to the environment [4]. As far as toxicity to humans, it has the same toxicity as clay does. This toxicity comes in stark contrast to Styrofoam which has been known to cause air pollution and waste when manufactured, is not created with biodegradable materials, and is unable to be digested by humans if ingested [1]. .

For the reasons my team has provided, we stand by our belief that both the mushroom packaging and the porous clay-organic composite material provided two good alternatives to the Styrofoam that is mainstream today.

**Exhibits:**

Diagram

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**Figure 1.** This image shows the process of making mushroom packaging [3].

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