FUNGI-BASED AUXETIC MATERIALS

A New Type of Mushroom Recipe

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We need to rethink the materials we use, from the types of clothes we buy to the construction bricks in our homes. Reducing the amount of waste that ends up in landfills is crucial for the future of our planet. The ***AUXFIM*** *project at UM proposes a solution by producing a sustainable yet strong auxetic mushroom-based composite material.*

Every year, the European Union generates 2.2 billion tonnes of waste, and in Malta, 86.2% of municipal waste goes to landfills. Landfills are problematic because they occupy useful space and pollute the environment – not only through the infiltration of toxins from the soil and water but also by creating the perfect conditions for decomposing waste to produce greenhouse gases. Escaping toxins and air pollutants can also affect the health of surrounding populations.

Protecting our health and the environment demands that we think about the life cycle of products. Which products can we consume less of? What can we exchange or give instead of throwing away? What can be reused or repurposed? Mindful consumption is important even in the production phase. How does the product's design shape how it will be used, repurposed, or discarded? Which raw materials can be replaced by biodegradable or energetically sustainable options?

MUSHROOMS AS BUILDING MATERIALS

If you are looking for an ingenious example of sustainable material development, look no further than the Auxetic Fungi Biomaterial (AUXFIM) project at UM, a collaboration between the Metamaterials Unit of the Faculty of Science and the Department of Physiology and Biochemistry at the Faculty of Medicine and Surgery. The team are working on producing biodegradable auxetic materials (materials that contract vertically when compressed horizontally) using mushrooms, promising a novel composite material that is durable, cost-effective, and good for the environment.

In conversation with **THINK**, the AUXFIM team, consisting of principal investigator Prof. Pierre-Sandre Farrugia and Prof. Ruben Gatt from the Materials Unit, together with Chev. Prof. Renald Blundell, from the Department of Physiology and Biochemistry, and research support officer Claudia Cadinu, explain how they are creating this unique material.

Mushrooms offer a plethora of benefits. Besides being biodegradable, they can withstand physical stress such as compression or bending. Some species even produce by-products during their growing stage that can be used for biomedical applications like drug production. Some species can also filtrate toxic elements, like heavy metals, when they come into contact with them in the soil or landfills.

For the purpose of the study, the team selected three mushroom species: *Ganoderma lucidum* (reishi mushroom), *Pleurotus ostreatus* (oyster mushroom), and *Trametes versicolor* (turkey tail mushroom). These species are naturally abundant, easily accessible, and have been extensively researched, meaning that the team has readily available information about cultivation protocols, safety concerns, and impact on composite properties. Blundell and Cadinu also explain that, according to existing literature, these fungi species do not produce harmful compounds, 'ensuring safety in biocomposite production'.

Oyster mushrooms are the main characters in many culinary dishes. They can grow on a wide variety of substrates, reducing production costs and, effectively, the cost of the final product. Reishi mushrooms are known for their anti-tumour properties, while turkey tails mushrooms are 'valued for their medicinal properties, including immunostimulant and antiviral effects,' Blundell and Cadinu point out.

A PROOF OF CONCEPT FOR AUXETIC BIOMATERIALS

Composites are materials formed by two or more elements that, when combined, result in a material with different properties from its individual components. In this case, the auxetic biomaterial will be composed of mushroom mycelia (the mushroom equivalent to plants' roots) and the substrate from which the fungi get their nutrients. While the mycelia grow, they start adhering to the substrate and forming solid structures, making it possible to use moulds to guide their growth and dictate the final shape of the biocomposite.

A system is auxetic if it expands vertically when pulled horizontally, meaning it becomes longer and wider when pulled, also known as a negative Poisson's Ratio. This differs from most natural materials, which typically have a positive Poisson's Ratio. Like elastics, materials with a positive Poisson's Ratio become longer but thinner when pulled.

A negative Poisson's Ratio translates into important physical properties, like improved shock absorption. Such properties give these materials incredible potential for applications not only in impact loading systems but also as smart particle filters (filters with pores that increase in area when pulled, making them easier to clean), fastening devices (like screws, rivets, and nails), dilators for medical applications (such as a stent inserted into the heart artery), and smart sporting accessories including running shoes and garments.

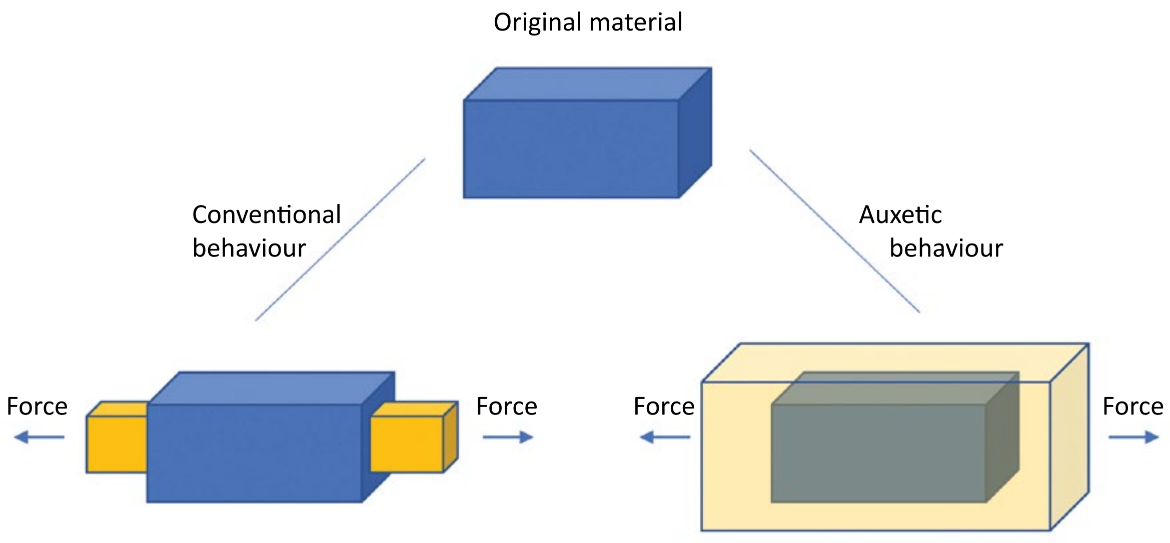

Illustration of the difference in behaviour between a conventional material (bottom left) and an auxetic one (bottom right)

Illustration courtesy of the AUXFIM Team

The AUXFIM team decided to test their biomaterial in the form of a pot for agriculture, a proof of concept showcasing the potential application of the new biocomposite. Can they produce a fungi-based material that not only has auxetic properties, but is also cost-effective and can be reproduced on a large scale with no alteration of its physical properties?

If successful, the pot will be biodegradable. Because the design of the mushroom-based composite should have auxetic properties, the pot should be able to expand with the roots of the plant. The pot can also provide nutrients to the plant itself. These features are particularly important for repotting, as they remove the need to transfer the plants from their nursery pot (usually made of plastic) to their final planter. Instead, the plant can simply be repotted with its nursery pot. Eventually, the biodegradable auxetic pot is meant to degrade into compost, reducing the use of plastic.

SHAPING FUNGI IN THE LAB

The team is now testing the best combination of mushroom mycelia and growing substrate, as well as different methods to grow and dry each species. The goal is to see how these variables affect the mechanical properties of the resulting biomaterial. For example, the figure below shows two biocomposites formed by the mycelia of two different mushroom species (the white block used turkey tail and the grey block used reishi).

Gatt explains that usually, fungi-based materials can sustain relatively large compressions but easily break under tension (like stretching). Farrugia adds that they would like their biocomposite to undergo relatively large deformations under both tension and compression. As such, the team wants to determine the best growth conditions and fungal species needed for a biocomposite that has these mechanical properties.

The shapes the mycelia grow into will also affect the properties of the final product, so the team is 3D printing moulds to test different shape configurations. Another factor affecting the final product is the substrate used to grow the fungi. Agricultural waste like sawdust, rye, straw, and even municipal organic waste can be used as substrates. Using materials that would otherwise be discarded in landfills as substrates is a great way to reduce waste and nurture a circular economy. Yet, these types of substrate can actually present a risk for the standardisation of the biocomposite because producers will not be able to control the composition of the substrate, which could potentially affect the characteristics of the final material.

At the moment, the research team is testing various growth conditions, substrates, and fungal species to see how they affect the properties of the biocomposites. Farrugia remarks that because 'this is the first study combining mushrooms with auxetic properties of composites, it is very hard to predict the outcomes. It is an anything can happen situation.' Ultimately, they hope to find the ideal mushroom species and processing methods to create a biodegradable, mushroom-based material that is strong, cost-effective, and easily applied to different industry sectors, and that can contribute to a zero-waste society.

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Mycelium biocomposites grown in rectangular shapes and dried using a microwave

Photo courtesy of the AUXFIM Team

The first batch of auxetic systems built using fungi

Photo courtesy of the AUXFIM Team