Development of Mycelium Based Inserts for Cricket Batting Pads

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1. Project overview

The findings presented in this report form part of the Circular Cricket Gear from Concept to Production Project [DC_Cricket], led by The Centre for Sustainable Design ® (CfSD) at the University for the Creative Arts (UCA). The project forms part of CfSD's Platform for Accelerating Sustainability in Cricket (PASIC) and has been funded by the UCA's UKRI IAA grant and ran from August 2025 to July 2026. The primary focus of the DC Cricket Project is the development of circular cricket batting gloves and pads that meet Decathlon's performance, quality, and manufacturing requirements while reducing reliance on virgin fossil fuel-based materials and improving product circularity. In this context, CfSD partnered with the University of Cambridge's Department of Architecture to explore the feasibility of developing mycelium-based composites (MBC) as an alternative sustainable material route for cricket batting pad inserts, which are conventionally made from petrochemically derived high-density polymer foam (HDF). The development of mycelium-based inserts for cricket batting pads follows on from the desk research completed by CfSD related to the feasibility of producing a bio-foam from local agricultural waste within a 50 km radius of the cricket gear manufacturing hub of Jalandhar. For further reference to the findings please refer to the report "Unlocking the Potential of Local Indian Biobased Materials for Circular Cricket Gear", which will be uploaded on the PASIC website.

Mycelium-based composites (MBCs) are bio-based materials produced by cultivating fungi on lignocellulosic substrates such as straw, sawdust, or hemp (Appels et al., 2019; Tan et al., 2026). Fungi are organisms such as mushrooms and moulds. As the fungus grows, it extends microscopic threads called hyphae, which form an interconnected network known as mycelium (Elsacker et al., 2019). This network binds the plant particles into a lightweight structural matrix (Tan et al., 2026). Heat treatment is then used to stop fungal growth and remove moisture (Elsacker et al., 2019). MBCs are actively explored as sustainable alternatives to petroleum-based foams for packaging, product design, and thermal insulation (Aiduang et al., 2022). However, their material properties depend heavily on the specific formulation, and dried samples are often brittle (Tan et al., 2026).

Terms used in this report:

1. "MBC": mycelium-based composite, is a material made by growing a fungus on a plant-based substrate.
2. "MBC inserts", or "inserts", are the MBC pieces made in this study to fit inside a cricket batting pad. Each insert was treated as one sample.
3. "Substrate" is the plant-based material on which the mycelium grows. "Inoculated substrate" is substrate to which living fungus has already been added.
4. "Cultivation" is the period during which the mycelium grows through the substrate and binds it into a solid, lightweight composite material.
5. "Demoulding" means removing an insert from its growing mould.
6. "Feedstock" is the raw plant material used to make substrate.
7. "Nominal" dimensions are the intended sizes set by the mould design.
8. "Density" is a material's mass per unit volume, given in this report in kg/m^3; for the same size, a lower density means a lighter piece. "Apparent dry density" is a dried insert's mass divided by its outer volume, including internal pores.

9. “Compression strength” indicates how strongly a material resists being compressed. It is given in megapascals (MPa), a unit of pressure; 1 MPa is about 10 kg resting on each square centimetre.

The research examines the feasibility of forming mycelium-based composites into the thin, elongated insert shapes required for protective sports equipment. In doing so, it investigates methods to convert agricultural-residue substrates (in this study, a commercially supplied inoculated substrate) into pad-size inserts through fungal growth, reusable moulds, assisted demoulding, and staged cultivation.

The samples comprise MBC inserts for two pairs of cricket batting pads, 28 inserts in total (16 long inserts: nominal length 420 mm, nominal thickness 15 mm; 12 short inserts: nominal length 300 mm, nominal thickness 15 mm). This report describes how these inserts were made and their physical characteristics after cultivation and drying. Their quality, dimensions, surface appearance and mass are presented below and compared with the HDF reference range. Overall, the MBC inserts were grown to the long, thin shape required for cricket batting pads (**Figure 1**), and most were lighter for their size than HDF. However, the MBC inserts were brittle. Apparent dry density ranged from 125 to 239 kg/m³, with means of 156 kg/m³ for long inserts and 194 kg/m³ for short inserts; 23 of the 28 inserts were below the HDF reference range of 200-250 kg/m³. Together, the inserts correspond to an estimated 156 g per pad, compared with 169 g of HDF per pad recorded in CfSD’s life cycle assessment of a pair of batting pads[1]. This estimate can be used when assembling and weighing a complete pad against the target of about 1 kg. Lower density could lead to lighter pads, an important requirement for cricket pads.

[1] Sanchez Moreno, L. and Charter, M. (2023) Streamlined Life Cycle Assessment: Pair of Cricket Batting Pads. The Centre for Sustainable Design, University for the Creative Arts. Available at: https://cfsd.org.uk/wp-content/uploads/2023/05/Final-Streamlined-LCA_batting-pads.pdf.

To check quality, each insert was inspected by eye for bending, damage and visible contamination, and its size was compared with the nominal dimensions (the mould's design size). The HDF density range and pad mass target are reference values specified by CfSD for this project. This study further explored a method for making individual MBC inserts for cricket batting pads. It identified two practical priorities before drying: keeping the inserts in shape and reducing contamination during handling. It also examined the feasibility of translating laboratory-scale fabrication into a regional production model using agricultural residues in India.



Figure 1 Photography of long group of mycelium-based composite (MBC) inserts developed for cricket batting pads (photo taken by the authors)

2. Objectives

As part of the DC_Cricket project, the overarching aim is to scope the technical and practical feasibility of mycelium-based composites (MBC) as a substitute for HDF in cricket gear (e.g. batting pads and gloves). Specific objectives are:

- Produce MBC samples grown on agricultural waste substrate(s).
- Characterise each sample by weight and density and benchmark against the HDF specification shared by CfSD (200–250 kg/m^3; ≤1.0 kg per pad).
- Estimate the compression strength of the MBC inserts (how strongly they resist being compressed) from published data on materials of similar density, as the mechanical indicator achievable within the project timescale.
- Assess the practical considerations of growing and moulding mycelium composites at production scale in Jalandhar, including feedstock availability (e.g. waste bagasse, cereal crop, rice husk), feedstock contamination/toxicity risk, and any relevant IP considerations.

3. Methodology and experimental development

3.1 Process overview

The MBC inserts were made in the following steps: designing and 3D printing the moulds, preparing the inoculated substrate, filling the moulds, letting the fungus grow (cultivation), drying the MBC inserts in the oven, and then weighing and measuring them. During fabrication, the researchers inspected each insert after demoulding, after a further 3 days of growth and after drying, recording any damage. The size of each insert was measured after drying. These observations were used to identify improvements to demoulding, size consistency and the number of usable inserts. A focused literature review was also carried out to understand key properties of mycelium-based composites, including material structure, density, compression, cushioning and moisture response (Appels et al., 2019; Elsacker et al., 2019; Liu, 2024; Rigobello and Ayres, 2022). Finally, published information on Jalandhar was reviewed to understand local agricultural feedstocks and the manufacturing context for cricket batting pads and gloves (NABARD, 2020/21; District Administration Jalandhar, n.d.) **Figure 2** shows the design and fabrication of mycelium-based batting pad inserts.

3.2 Materials and sample configuration

A commercially standardised, inoculated substrate [2] supplied by GROWN.bio and based on *Ganoderma lucidum (GL)* was used to produce sample materials. GROWN.bio is the European licensee of Ecovative Design LLC (GROWN.bio, n.d.b). The dry-mass formulation used for this study comprised corn stover (40–45%), hemp pith (40–45%), wheat flour (1–5%) and a proprietary additive (1–5%). Before mould filling, the inoculated substrate was loosened and combined with the supplier's sculpting mix[3] to improve cohesion and formability (GROWN.bio, n.d.a).

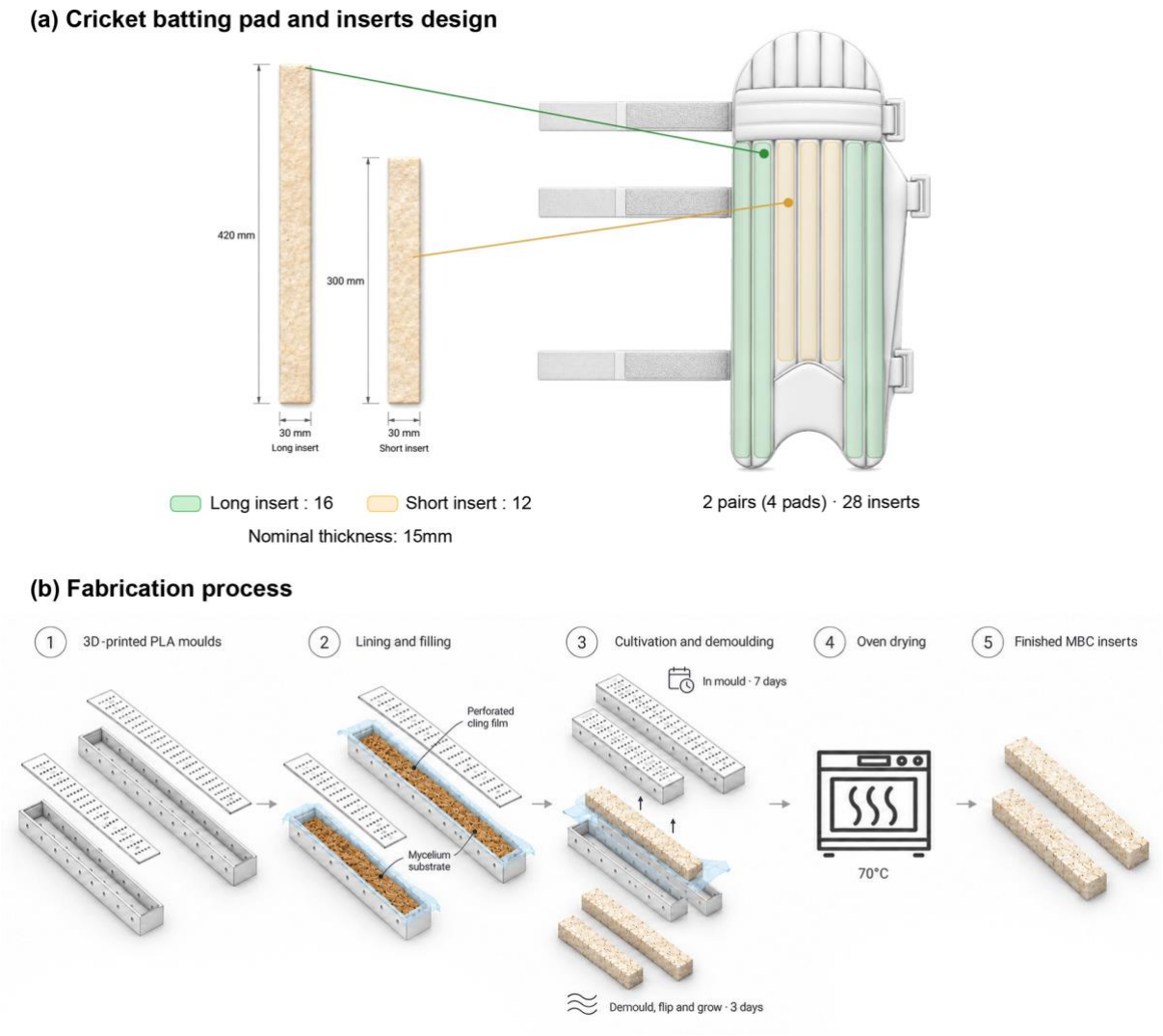


Figure 2 (a) Cricket batting pads layout and MBC insert design. (b) Fabrication using perforated 3D printed PLA moulds and cling-film liners, followed by cultivation, demoulding, further surface growth and drying at 70°C.

[2] The inoculated substrate: the supplier has already introduced the living fungus into the plant-based substrate (GROWN.bio.n.d.a).

[3] Sculpting mix: a powder that turns the substrate into a clay-like material that can be shaped (GROWN.bio, n.d.c).

As a white-rot[4] fungus, *GL* can utilise plant-based material and form fine, branching hyphae[5]. Its chitin- and glucan[6]-containing hyphae develop an interwoven network that binds substrate particles and can form a compact, microporous surface layer. Haneef et al. (2017) showed that the stiffness and stretch of *GL* mycelial films vary with the substrate, while Rigobello and Ayres (2022) demonstrated that particle size and fibre orientation can modify the compressive behaviour of *GL-based mycelium* composites. GROWN.bio uses GL in its inoculated substrate, a ready-to-use and commercially established product (GROWN.bio, n.d.c), which allowed this study to concentrate on forming the long, slender insert shape. Further innovation can focus on mould geometry, growth conditions and post-processing, alongside subsequent trials with alternative substrates.

The insert lengths were derived from the internal layout of the cricket batting pad. Each pair required eight long and six short inserts. Two pairs were prepared, giving 16 long and 12 short inserts. **Figure 2(a)** shows their arrangement, with nominal dimensions of 420 × 30 × 15 mm and 300 × 30 × 15 mm, respectively.

3.3 Mould design and fabrication

The moulds were digitally modelled and fabricated by 3D printing using polylactic acid (PLA) – in practice other mould materials, such as medium-density fibreboard or recycled plastics may also be suitable. Each mould was designed as a reusable assembly that could be opened easily to support demoulding without damaging the elongated MBC inserts. Uniformly distributed perforations were incorporated into the mould surfaces to maintain air circulation during cultivation. The mould cavity dimensions corresponded to the required long and short insert shapes, as shown in **Figure 2(b)**.

3.4 Sample preparation and cultivation

Before filling, the transplantation area and mould components were surface cleaned using a 75% alcohol sanitiser spray. The prepared inoculated substrate was manually distributed into the cavities and compacted along their length. Consistent packing was used to limit local voids and establish comparable starting conditions between inserts.

The filled moulds were cultivated in darkness for seven days at 22 ± 2°C and 70 ± 5% relative humidity. The inserts were then released, inspected for cohesion and surface coverage, and turned to expose their mould-contact faces. A further 3 days of cultivation allowed surface colonisation and local regrowth before drying, as shown in **Figure 2(b)**.

Initial fabrication trials encountered demoulding difficulties due to the slender geometry of the MBC inserts, which exhibited a high length-to-thickness aspect ratio. Because the inserts are long, slender strips, the colonised substrates lacked flexural strength[7] and easily broke across the middle when demoulded (**Figure 3(a)**). In the subsequent iteration, this failure mode was resolved by lining the rigid

[4] White-rot fungus: a wood-decaying fungus that can break down lignin-rich plant matter (Lingam et al., 2023; Camilleri et al., 2025).

[5] Hyphae: the thin filaments of a fungus, which form the interwoven network called mycelium (Elsacker et al., 2019; Aiduang et al., 2022).

[6] Chitin and glucans: natural polymers in the walls of hyphae; chitin provides rigidity (Gow et al., 2017; Aiduang et al., 2022).

[7] Flexural strength: the stress at which a sample fractures when bent (Aiduang et al., 2022).

moulds with a perforated cling film. The perforations ensured necessary aeration for accelerated, uniform surface growth, while the film functioned as an effective release interface. This modification resolved the midsection breakage at demoulding and yielded intact inserts.

3.5 Drying and physical characterisation

After a total of 10 days of cultivation, the fungus had visibly colonised and turned the surface white. The MBC inserts were thermally dried at 70°C. Each cycle comprised 3–4 hours in the oven followed by 12 hours at room temperature for moisture redistribution and further air-drying. The cycle was repeated until constant dry mass was obtained. Dry mass was measured in grams using a balance with a resolution of 0.01 g.

Length, width and thickness were each measured at three evenly distributed positions on each MBC insert. The three readings for each dimension were averaged because the inserts were not perfectly uniform. The same measurement and calculation procedure was applied to all 28 samples.

The outer volume V_{app} of each dried insert was estimated. Then, apparent dry density ρ_{app} was calculated for each insert. This value includes the grown surface and internal pores and provides a consistent way to compare inserts of irregular shape. Dimensional change relative to the nominal mould dimensions was expressed as nominal-to-dry contraction[8] C_d. Positive values indicate a dry dimension below nominal; negative values indicate a dimension above nominal. In plain terms, these figures show how close the dried MBC inserts came to the size of the mould; the difference reflects the combined effects of filling, growth and drying. Results were summarised separately for long and short inserts using the mean, standard deviation[9] and range. All 28 inserts were included, and the mean density for each size was calculated from the individual insert densities. Bending, contamination and damage were recorded as separate observation categories, allowing an MBC insert to appear in more than one category.

4. Outcomes of sample development

4.1 Growth and demoulding observations

During the first one to five days, mycelium developed within the inoculated substrate packed into the 3d-printed moulds. Areas of the inserts on the surface that exposed to air formed a denser surface skin that grew beyond the packed boundary. Demoulding before this skin fully covered the mould's holes and edges made the insert easier to separate from the mould. Then, the inserts were flipped, exposing the faces previously in contact with the mould to air for a further three days of cultivation.

Demoulding showed how easily the long, slender inserts could be damaged. Wet inserts were fragile, and mycelium growing around the mould's holes and edges made them harder to remove. The long

[8] Nominal-to-dry contraction: Cd = (nominal − dry) / nominal × 100%, calculated in this study (Appendix A). For example, 410 mm against a nominal 420 mm gives 2.38%.

[9] Standard deviation (SD): how widely values spread around the mean. Range: the largest value minus the smallest (NIST, n.d.).

inserts required support along their length because pulling at one point could damage the middle section **(Figure 3(a)**). Continued growth after demoulding re-covered some areas of minor damage, providing a useful recovery stage before final drying. This was only a visual observation: the surface looked continuous again, but recovery of strength was not tested.

Some MBC inserts developed sparse growth under apparently similar cultivation conditions. Contamination occurs when other microorganisms, such as unwanted moulds, grow on the material and compete with the cultivated fungus. Moulds often reported on MBC include *Trichoderma*, *Penicillium* and *Rhizopus* (Houette et al., 2022; Irbe et al., 2022; Mohseni et al., 2023), and GL



Figure 3 Mycelium-based composites inserts: (a) demoulding process after seven days of cultivation, with breakage across the middle of an insert marked; (b) short inserts showing mycelial surface coverage; (c) long inserts showing variations in surface coverage and texture; (d) contamination on an MBC insert (S-5), visible as a yellow-brown area.

composites grown on hemp are among the strains most susceptible to *Trichoderma* (Verhelst et al., 2024). Contamination has been reported to occur mostly in the later phases of colonisation (Mohseni et al., 2023). In this study, visible contamination was recorded on five MBC inserts (one long insert, and four short inserts, see **Appendix A** and **Figure 3 (d)**). It appeared as yellow-brown patches on the surface and was mainly noticed during the later stage, after demoulding, flipping and renewed air exposure. This timing identifies transfer and exposed growth as priorities for cleaner handling and protected ventilation. The observation records in **Appendix A** describe visible contamination rather than identifying the contaminating organisms.

4.2 Dry density and dimensional outcomes

The nominal dimensions of the MBC inserts were 420 × 30 × 15 mm for the long inserts and 300 × 30 × 15 mm for the short inserts (length × width × thickness). The long inserts had a lower mean apparent dry density than the short inserts, despite their greater individual mass. **Table 1** summarises the physical results; **Appendix A** lists every insert and its observations. Both sizes were produced: **Figure 3(b)** shows the short inserts and **Figure 3(c)** shows the long inserts.

Table 1 Physical characteristics of the dried inserts

Characteristic	**Long inserts**	**Short inserts**
Recorded samples	16	12
Dry mass range / g	18.66–33.94	11.09–19.42
Total dry mass / g	428.21	194.08
Apparent dry density / kg/m³	155.81 ± 22.21	194.16 ± 20.82
Density range / kg/m³	125.13–204.79	164.30–239.00
Mean nominal-to-dry volume shrinkage / %	8.60 ± 16.22	38.08 ± 7.91

Values with ± report the sample mean and standard deviation. Volume shrinkage was calculated for each insert relative to its nominal design volume, then averaged for each insert size. Positive values indicate a smaller dry volume. Individual dry dimensions (length, width, and thickness measured after drying to constant mass) are reported in **Appendix** A.

Five inserts fell within the 200–250 kg/m³ HDF reference range, comprising one long and four short inserts. The remaining 23 inserts were below 200 kg/m³. All 28 inserts exhibited drying shrinkage post-baking; accounting for shrinkage factors in mould design is therefore critical for achieving target nominal dimensions.

Overall dry volume[10] fell below nominal by an average of 8.60% for long inserts and 38.08% for short inserts, although six long inserts had a volume above nominal, mainly because they were thicker than nominal. Long inserts averaged 405.00 mm in length (3.57% contraction), while short inserts averaged 277.33 mm in length (7.56% contraction). Width contraction was also lower for the long inserts, so they stayed closer to their nominal length and width.

Thickness varied widely. Short inserts ranged from 10–14 mm, all below the nominal 15 mm, whereas long inserts ranged from 10–20 mm, with seven long inserts exceeding the nominal 15 mm. In practice, thickness affects how an insert fits inside the pad and how much material is available for cushioning, so filling and growth need closer control. The short inserts were more consistent in width and thickness than the long inserts, although they were thinner than nominal. The mean densities of the long and short inserts were 22–38% and 3–22% lower, respectively, than the HDF reference range of 200–250 kg/m³. In practice, lower density means an insert of the same size weighs less, which supports the aim of a lighter pad; the weight of a complete pad also depends on its other components.

4.3 Compression strength estimates from published studies

Compression strength indicates how strongly a material resists being compressed. To estimate this property for the batting pad inserts, published results for mycelium-based composites made with plant materials, including straw, sawdust and rice husk, were examined using the dataset compiled by Tan et al. (2026). Of the 187 records, 167 were retained after removing results with unclear measurements, sources or density information, and results from repeated loading.

For each batting pad insert size (long and short), published materials with densities within 25 kg/m³ above or below the mean density measured for that size were selected. Their compression strengths were arranged from lowest to highest, and the middle value (the median) was used as the estimate. Because few matching results were available for *Ganoderma* (the fungal genus that includes GL) alone, materials grown using other fungal genera were also included.

The estimated compression strengths were 0.224 MPa for long MBC inserts and 0.218 MPa for short MBC inserts. **Table 2** also gives the range covering the middle half (the interquartile range, IQR[11]) of the selected published results, showing how much these results varied. These values are estimates from published materials; the MBC inserts were not compression-tested. **Appendix A** provides estimates based on each individual MBC insert's density. **Figure 4 compares** 38 foam grades: EPS (Insulfoam, 2020), XPS (Austrotherm, 2018), rigid PU (General Plastics, 2022), SAN (Gurit, 2023) and PVC/IPN (Diab, 2020). EPS/XPS values are declared minima; others are nominal or typical strengths. PU data are for 24°C, parallel to rise. HDF is a density benchmark. **Appendix B** provides the detailed method of compression estimation. Published materials with a similar density to these inserts typically reached a compression strength of about 0.2 MPa (roughly 2 kg resting on each square centimetre). This is only an initial indication to guide testing.

[10] Dry volume: the outer volume of each dried MBC insert in this study, estimated from length × width × thickness and including internal pores.

[11] Interquartile range (IQR): the range covering the middle 50% of values, from the 25th to the 75th percentile.

Table 2 Density-matched compression estimates

Insert size	Density window kg/m³	Records / studies	Median estimate MPa	Literature IQR MPa
Long	130.81–180.81	10 / 5	0.224	0.164–0.398
Short	169.16–219.16	25 / 9	0.218	0.025–0.255

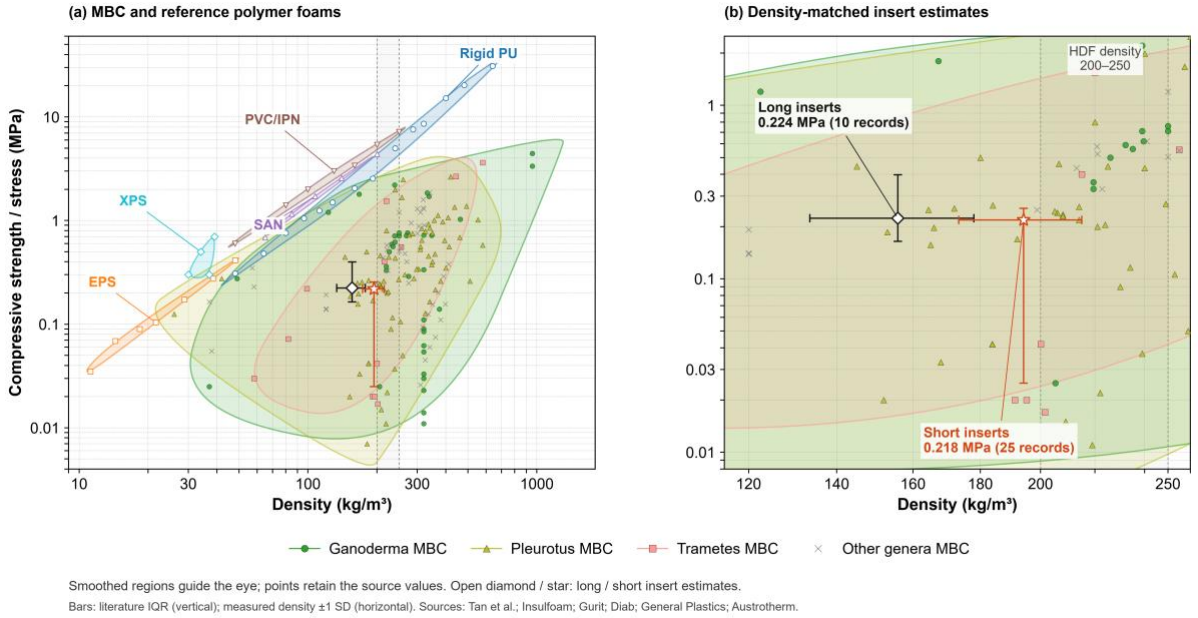


Figure 4 Figure 4 Density–compression Ashby comparison, which maps compression strength against density for MBC and reference foams. (a) MBC literature data (Tan et al., 2026) and reference foam grades: EPS, XPS, rigid PU, SAN and PVC/IPN. Smoothed regions follow the review plotting method; points retain source values. (b) Enlarged insert-density region. Open diamond and star: long and short insert estimates; vertical bars: literature IQR; horizontal bars: measured density ±1 SD. The grey band marks the HDF reference range. Points further right are denser (heavier for the same size) and points higher up resist compression more strongly.

5. Material properties and manufacturing development

5.1 Geometry and material structure

The long, slender inserts need support along their length during demoulding and drying. The measured differences from nominal dimensions can guide adjustments to the mould, while controlled filling and perforated drying supports, such as trays or mesh that support the full length of each insert while allowing airflow, can improve the final fit. The choice of substrate and pressing parameters also affect how the material responds to mechanical loads and moisture (Appels et al., 2019). These processing choices could help make the inserts strong enough to handle and fit into a cricket batting pad, while remaining able to compress and absorb energy when the pad is struck during play.

Further literature review should focus on flexibility and recovery after repeated bending and compression. Studies on building insulation and protective packaging provide useful starting points (Alaux et al., 2024; Liu, 2024). Liu (2024) found that the packaging foam tested had lower rebound resilience than expanded polyethylene and lost cushioning performance over repeated drops; moisture content also affected its cushioning behaviour. For batting pads, this raises three questions for testing: whether the inserts keep cushioning after repeated ball impacts, whether they recover their shape, and whether sweat or damp conditions change their performance. Conceptual designs could explore a firmer, loofah-like network with more internal connections. Fabrication trials could vary particle size, packing, growth conditions and post-processing to assess flexibility and shape recovery (Appels et al., 2019; Rigobello and Ayres, 2022).

5.2 Growing a block and cutting before final drying

An alternative is to grow a larger block, cut it into inserts once the material holds together well enough, supporting it during cutting, allowing the cut faces to regrow, and then dry the inserts. This could mean fewer demoulding steps and use continued growth to seal the cut faces. The timing of cutting is critical: wet material can deform, while dried edges can crumble.

Elsacker et al. (2021) showed that large mycelium blocks can be grown, cut with an abrasive wire and joined by further fungal growth, for use as formwork (moulds used in construction). A trial comparing inserts grown in individual moulds with inserts cut from blocks should assess how intact the edges are, how close the dimensions are to nominal, and how many usable inserts are obtained.

5.3 Moisture management and textile integration

A breathable textile sleeve could protect the insert surface, contain loose particles and support drying between uses. Kaiser et al. (2023) reported compression failure stresses[12] of 0.97 MPa with textile wrap and 0.71 MPa without it, for a mycelium paste (“mycocrete”) developed for architecture. These values show that a textile wrap can strengthen mycelium material; pad-specific sleeve designs should be assessed for moisture response, repeated-impact behaviour and added mass.

5.4 Cleaner transfer and efficient drying

Contamination observed mainly after demoulding makes clean transfer trays, sanitised contact surfaces and protected ventilation immediate manufacturing priorities. Efficient oven loading and a consistent drying endpoint can improve energy use per usable insert. This matters because, in the life cycle assessment of mycelium insulation by Alaux et al. (2024), electricity used in manufacturing was a main source of greenhouse gas emissions. Recording the energy used for growth and drying would allow the same check to be made for the inserts.

[12] Compression failure stress: the stress at which a sample fails when compressed, as reported by Kaiser et al. (2023).

6. Agricultural feedstocks and production in India

6.1 Regional sourcing options

Jalandhar, Punjab, India, provides a starting point for a local feedstock trial. The 2020–21 district credit plan for Jalandhar, published by the National Bank for Agriculture and Rural Development (NABARD), identifies wheat, paddy, sugarcane and maize among the principal crops (NABARD, 2020/21). These profiles identify candidate residue streams; current recovery volumes and competing uses could be found in the report “Unlocking the Potential of Local Indian Biobased Materials for Circular Cricket Gear”. **Table 3** shortlists candidate residues for regional trials.

Table 3 Feedstock shortlist for regional trials

Candidate residue	Selection basis	Production focus
Wheat and rice straw	Jalandhar crop profile; rice straw studied by Peng et al. (2023).	Specify residue type, particle grading, clean storage and seasonal collection.
Sugarcane bagasse	Studied by Peng et al. (2023); potential processor-based supply.	Check incoming moisture, storage stability, transport and existing fuel uses.
Maize residues	Jalandhar maize production; corn straw studied by Peng et al. (2023).	Keep stalk, husk and cob streams distinct; compare growth and filling behaviour.

The regional trial should begin with a small number of defined feedstocks rather than an unrestricted mixture of available residues. Peng et al. (2023) showed that fungal growth and final material properties changed with the plant residue used, in tests across rice straw, bagasse, coir pith, sawdust and corn straw. Keeping the fungal strain, filling mass and insert shape constant would allow the comparison of local residues to identify useful changes in growth and final insert quality.

6.2 Production and scale up

Reusable moulds could support the production of multiple MBC inserts at the same time. Growing larger blocks and cutting them into inserts offers another possible route to increase output. A local trial could compare these routes using the insert-by-insert measurement and observation record in **Appendix** A as a template. The comparison should record how long each mould is occupied, the labour needed for filling and demoulding, and the number of usable inserts obtained after drying. At present, the main barrier to scaling up is the brittleness of the dried MBC inserts. The priority is therefore to improve their strength and flexibility. Scaling up would also require sufficient space for cultivation, clean handling and drying equipment. Growth time, contamination, variation between batches and drying energy would affect production capacity and cost. Consistent substrate preparation, filling and drying procedures would help control these sources of variation. Each batch should be checked for dimensions, damage and visible contamination. Production costs should include materials, labour,

energy, mould cleaning and reuse, and rejected inserts, so that the cost per usable insert can be compared.

Further material development should aim to achieve the flexibility and recovery after compression needed for batting pads and gloves, alongside the target density. The type and mix of plant residues, how tightly the material is packed into the moulds, and treatments after growth such as pressing or controlled drying could be adjusted to explore these properties (Appels et al., 2019). Candidate materials should be compared directly with the HDF reference under the same bending and repeated-compression conditions. This would show which formulations can bend, resist compression and recover their shape while retaining the required dimensions and low mass.

7. Conclusions and recommendations for further development

In summary, this study showed that mycelium-based composites (MBC) can be grown into the long, thin shapes needed for cricket batting pad inserts, which are called MBC inserts in this study. Most of dried MBC inserts were dense than the HDF reference range. The main limitation is that the dried MBC inserts are light but brittle and snap easily. The next steps are to make the MBC inserts tougher and more flexible to fabricate, to test how well it protects against impact, and then to trial ways of producing them at larger scale in Jalandhar.

The project produced and characterised 28 pad-sized MBC inserts through reusable PLA moulding, staged cultivation and oven-drying. The dry measurements provide a baseline for insert mass and link the final dimensions to practical fabrication observations. Mean apparent dry density was 155.81 kg/m³ for long inserts and 194.16 kg/m³ for short inserts. The estimated insert mass was about 156 g per pad, before adding the other pad components.

The long inserts kept closer to their nominal length and width, while the short inserts were more consistent in width and thickness. Both sizes were produced (**Figure 3(b)** and **(c)**; **Appendix** A). Thickness and bending need to be controlled separately, because the inserts shrank on drying while, in places, the fungus grew beyond the mould boundary. Perforated cling-film liners and support when moving the inserts are practical starting points for improving handling. The most important production question is whether to grow each insert in its own mould or to grow a larger block and cut it into inserts while the fungus is still alive. Cutting before final drying could produce several inserts at once and allow the cut edges to regrow. A side-by-side trial should compare how well each route meets the nominal size, keeps edges intact, avoids contamination and yields usable inserts.

Development of the insert material should consider how the insert works within the complete batting pad assembly. Comparison with published materials of similar density placed both insert sizes near 0.22 MPa, a useful starting point for direct compression testing. Nonetheless, the inserts made with this method were brittle and snapped easily, because of their slender shape and local variations in the mycelium network. Making them wider or thicker could make them easier to handle, but protection against impact ultimately depends on how well the material recovers after compression.

Growing larger blocks and cutting them to size (Section 5.2) could also address these limitations. Cutting while the fungus is still growing lets the cut faces regrow and seal, but the soft, wet material needs support to avoid distortion; cutting after drying is easier but can leave crumbly edges that do not regrow. Future trials should therefore test cutting partly grown blocks with a guided blade,

followed by a short further growth stage to form an intact outer skin. Improving elasticity and recovery after repeated compression is a priority for further development. Islam et al. (2018) reported elastic behaviour at small strains and hysteresis and stress softening[13] under cyclic compression in mycelium particulate composites. The mycelium acts as a natural binder, forming a network that connects the agricultural-residue particles. A more interconnected, firmer loofah-like structure, or a more flexible matrix, could therefore be explored through substrate and process changes. Any increase in retained moisture should be assessed for its effects on flexibility, dimensional stability and storage behaviour.

Impact testing was not carried out in this study because a suitable rig was unavailable. The long, thin inserts also differed from the thick, square samples envisaged for material-level impact testing. Further work should select a suitable loading arrangement and specimen geometry for cricket pads and gloves, including tests on the assembled protective equipment. Relevant product standards include BS 6183-3:2000 for leg protectors and BS 6183-4:2001 for batting gloves (BSI, 2000; 2001); the applicable geometry, conditioning and test requirements should be checked in the full standards.

For production in Jalandhar, reusable moulds or larger blocks cut into multiple inserts offer possible routes to increase output. The main challenges are consistent growth, contamination control, drying capacity and cost per usable insert. Further material development should assess density, flexibility, feedstock toxicity and recovery after repeated compression against the HDF reference.

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Appendix A MBC insert samples measurements

ID	Length mm	Width mm	Thickness mm	Mass g	Density kg/m³	Length contraction %	Estimated compressive strength MPa	Observation
Long Inserts								
L-1	410	27	10	22.67	204.79	2.38	0.238	
L-2	405	28	18	33.53	164.27	3.57	0.186	
L-3	415	28	18	28.84	137.88	1.19	0.186	
L-4	400	30	15	26.99	149.94	4.76	0.197	
L-5	410	29	15	30.81	172.75	2.38	0.157	Bending
L-6	395	25	15	18.66	125.97	5.95	0.192	Bending
L-7	400	28	17	29.82	156.62	4.76	0.197	
L-8	410	27	16	32.17	181.63	2.38	0.163	Partial Damage
L-9	400	26	14	21.85	150.07	4.76	0.197	Contamination
L-10	410	29	16	33.94	178.41	2.38	0.100	
L-11	405	27	15	28.30	172.53	3.57	0.157	Damage
L-12	400	25	15	20.36	135.73	4.76	0.186	Minor damage
L-13	410	28	17	30.85	158.08	2.38	0.197	
L-14	400	27	14	21.71	143.58	4.76	0.189	
L-15	400	25	14	18.98	135.57	4.76	0.186	
L-16	410	28	20	28.73	125.13	2.38	0.192	
Short Inserts								
S-1	280	25	10	16.73	239.00	6.67	0.605*	
S-2	270	25	10	11.09	164.30	10.00	0.186	
S-3	283	25	13	19.42	211.14	5.67	0.430*	
S-4	275	26	13	15.86	170.63	8.33	0.157	

ID	Length mm	Width mm	Thickness mm	Mass g	Density kg/m³	Length contraction %	Estimated compressive strength MPa	Observation
S-5	280	25	14	18.17	185.41	6.67	0.169	Bending; contamination
S-6	285	25	13	18.40	198.65	5.00	0.235	Contamination
S-7	280	25	13	15.56	170.99	6.67	0.157	Damage
S-8	275	25	12	16.81	203.76	8.33	0.238	Bending
S-9	280	25	12	15.68	186.67	6.67	0.169	
S-10	270	25	10	14.11	209.04	10.00	0.360*	Damage
S-11	270	24	12	14.95	192.26	10.00	0.224	Contamination
S-12	280	26	12	17.30	198.03	6.67	0.235	Bending; contamination

Estimated strength is the median of retained MBC literature records within ±25 kg/m³ of each specimen's unrounded density. * *Ganoderma* results only (at least five matches); other values use all genera. These are literature-based screening estimates.

Appendix B Compression estimation method

The same density comparison was used for each insert in **Table 2** and for each individual insert above. The equation below gives the median compression strength of published materials whose density lies within ±25 kg/m³ of the measured density.

$$\hat{\sigma}_{c,g} = \text{median}\{\sigma_{c,j} : |\rho_j - \bar{\rho}_g| \leq 25\ \text{kg/m}^3\} \quad (1)$$

Here, *j* identifies a published result, and *g* identifies an insert group. For an individual insert, its density replaces the mean for that size. Each size had fewer than five matching Ganoderma records, so Table 2 includes results from all fungal genera. The reported range covers the middle half of the selected published strengths.

To check whether studies contributing more results affected the estimates, a second calculation gave every study equal weight. A median was first calculated for each study, then the median of those study values was taken. This gave 0.250 MPa for long inserts and 0.238 MPa for short inserts. Changing which studies were included affected the short-insert estimate more than the long-insert estimate.