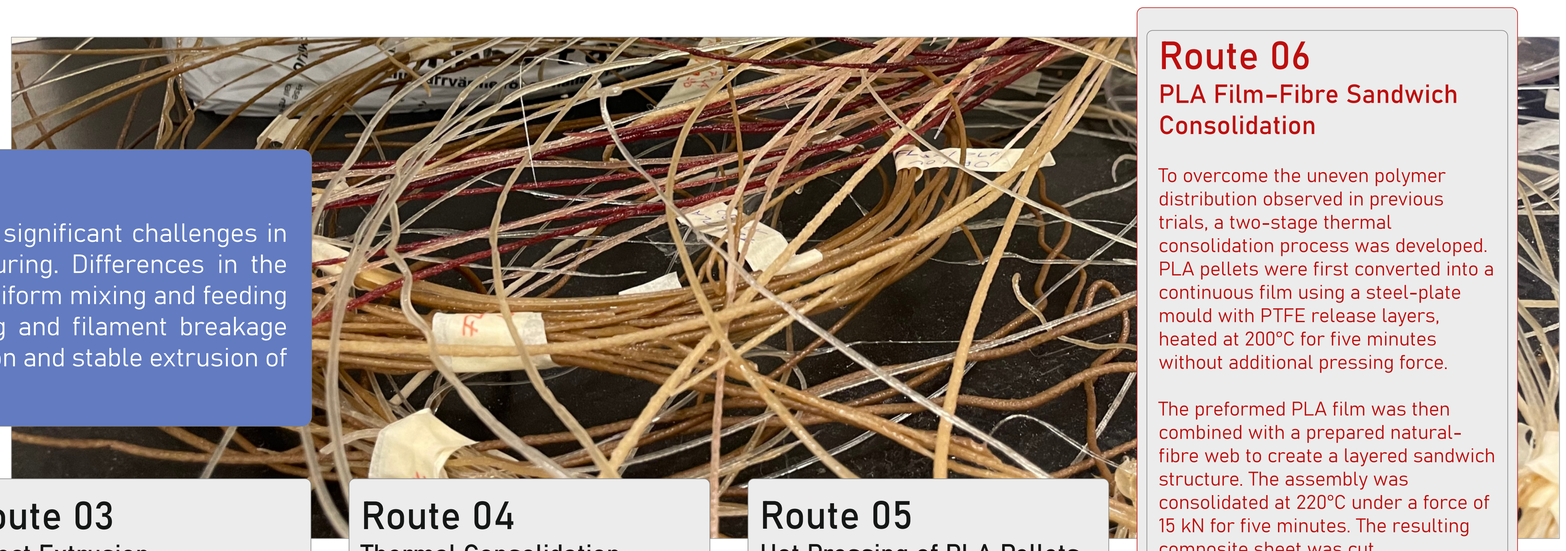
Development of Sustainable Wool-PLA Composite Filament for Additive Manufacturing Applications

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Research Challenge

The incorporation of natural fibres into polylactic acid (PLA) presents significant challenges in producing homogeneous composite feedstock for additive manufacturing. Differences in the physical characteristics of PLA granules and wool fibres complicate uniform mixing and feeding during extrusion. Uneven fibre distribution, moisture-related foaming and filament breakage compromise process continuity and dimensional consistency.corporation and stable extrusion of wool–PLA composite filament.

Route 01
Direct Mixing and Extrusion

The initial approach involved manually mixing pre-cut recycled wool fibres (10 wt.%) with PLA pellets (90 wt.%) before feeding the mixture directly into the extruder. This method eliminated the need for preliminary material consolidation and provided a straightforward starting point for composite filament production.

However, the differences in physical form between the polymer pellets and wool fibres prevented uniform distribution during feeding and extrusion. The resulting filament exhibited an inhomogeneous structure, increased brittleness and frequent breakage, making continuous extrusion and winding difficult. Adjustments to cooling conditions provided only limited improvement.

These observations highlighted the need for more effective fibre dispersion and preliminary integration of the constituent materials before extrusion.

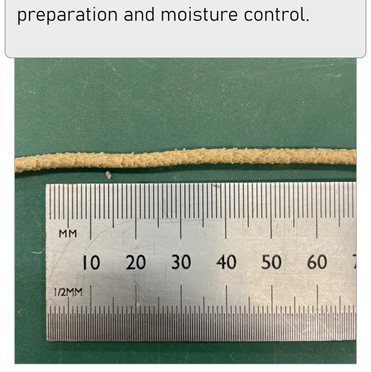


Route 02
Joint Milling and Extrusion

To improve fibre distribution, PLA pellets and natural fibres were subjected to joint mechanical milling before extrusion. An IKA M 20 batch mill was used in 15-second cycles separated by 20-second intervals to prevent overheating. Fibre concentrations of 1, 3, 5 and 10 wt.% were investigated.

Although milling improved the apparent uniformity of the feedstock, satisfactory mixing was achieved only at fibre contents of up to 3 wt.%. At higher concentrations, unbound fibres remained separated from the PLA particles, causing difficulties during feeding into the extruder.

The experiment demonstrated the limitations of mechanical mixing and indicated the need for a more effective method of integrating fibres with the polymer matrix.



Route 03
Direct Extrusion from Nonwoven Web

To overcome the limitations of mixing loose fibres with PLA pellets, a preformed nonwoven web containing PLA and natural fibres in a 50:50 weight ratio was introduced directly into the extruder. This approach eliminated the need for mechanical milling and enabled a substantially higher fibre content in the feedstock.

The experiment produced a relatively homogeneous filament with distinctive visual characteristics. However, moisture retained within the nonwoven structure, associated with the hygroscopic nature of the fibres, caused foaming as the molten material exited the extrusion nozzle. Furthermore, the PLA fibres used in the nonwoven differed from the polymer grade selected for filament production.

This demonstrated the potential of fibrous structures while highlighting the need for better feedstock preparation and moisture control.



Route 04
Thermal Consolidation of Nonwoven Web

To improve feedstock handling, a preformed nonwoven web containing PLA and natural fibres was thermally consolidated before extrusion. A 50:50 PLA–NF nonwoven was placed in a brass mould and hot-pressed at 200°C under a force of 50 kN for five minutes. The resulting composite sheet was cut into strips and pelletised into approximately 3 × 5 mm particles suitable for extruder feeding.

Unlike direct extrusion from loose nonwoven material, this approach introduced a preliminary consolidation stage, producing a more manageable feedstock. However, the method still relied on PLA fibres incorporated into the nonwoven rather than the selected PLA pellet grade.

The experiment established thermal consolidation and subsequent pelletisation as a promising route towards more controlled preparation of composite feedstock.



Route 05
Hot Pressing of PLA Pellets with Loose Fibres

To incorporate the selected PLA grade into the composite feedstock, natural fibres were combined with PLA granules and subjected to thermal compression. Mixtures containing 10 and 20 wt.% fibres, including recycled wool, were prepared in a brass mould. The materials were heated to 200°C in three-minute cycles, with the applied force gradually increased to 15 kN. The resulting composite sheets were cut and ground to produce extrusion feedstock.

Although this approach enabled the use of PLA pellets, the polymer was distributed unevenly throughout the fibrous structure. Increasing the pressing force to 50 kN caused excessive polymer displacement from the mould.

These limitations demonstrated the need for more uniform polymer distribution before thermal consolidation, leading to the development of a preformed PLA film.





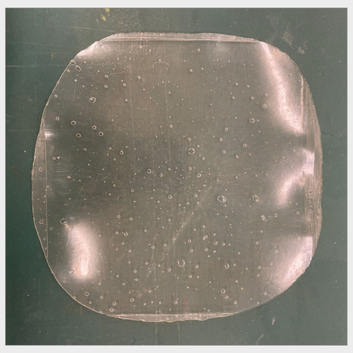
Route 06
PLA Film–Fibre Sandwich Consolidation

To overcome the uneven polymer distribution observed in previous trials, a two-stage thermal consolidation process was developed. PLA pellets were first converted into a continuous film using a steel-plate mould with PTFE release layers, heated at 200°C for five minutes without additional pressing force.

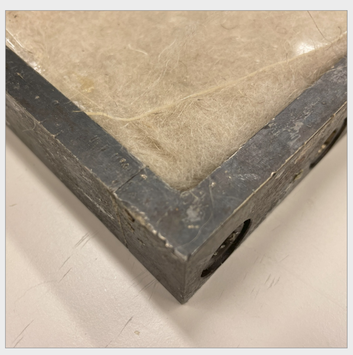
The preformed PLA film was then combined with a prepared natural-fibre web to create a layered sandwich structure. The assembly was consolidated at 220°C under a force of 15 kN for five minutes. The resulting composite sheet was cut, mechanically ground and introduced into the extruder as prepared feedstock.

By separating polymer film formation from fibre consolidation, this approach addressed the limitations of directly pressing loose PLA pellets onto fibres. It also enabled the use of the selected PLA grade while providing a more controlled arrangement of the constituent materials before extrusion.











Results and Evaluation

The experimental programme focused on the initial incorporation of virgin and recycled wool fibres into a PLA matrix at different weight concentrations. No plasticisers, coupling agents, silane treatments or other chemical modifiers were employed. Instead, the investigation concentrated on mechanical and thermomechanical feedstock preparation methods. This approach was intended to assess the effects of fibre incorporation on filament processing and material properties without introducing additional variables associated with chemical modification.

Conclusions

Feasibility

The experimental programme demonstrated the feasibility of incorporating natural fibres, including wool, into PLA-based feedstock for additive manufacturing. Successive trials revealed the limitations of direct mixing and established the importance of feedstock preparation before extrusion.

Technological Development

The developed sandwich technology provides a structured method of combining PLA with fibrous materials through thermal consolidation, without chemical coupling agents or plasticisers. This approach enables the investigation of fibre–polymer composites without additional chemical modification.

Further Research

Further research should focus on improving filament homogeneity, extrusion stability and printability, alongside systematic evaluation of the mechanical properties of wool–PLA composites at different fibre concentrations.

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