

# Coconut Fibre Reinforced Photopolymer Composites via Stereolithography: Feasibility and Mechanical Performance

Valeria Palomba<sup>1,a</sup>, Antonio Fotia<sup>1,b</sup>, Giulia Palomba<sup>1,2,c\*</sup>,  
Pasqualino Corigliano<sup>1,2,d</sup>, Mohamed Chairi<sup>1,e</sup> and Guido Di Bella<sup>1,2,f</sup>

<sup>1</sup>CNR ITAE, Salita S. Lucia sopra Contesse 5, 98126 Messina, Italy

<sup>2</sup>Department of Engineering, University of Messina, Contrada di Dio, 98166 Messina, Italy

<sup>a</sup>valeria.palomba@cnr.it, <sup>b</sup>antonio.fotia@cnr.it, <sup>c</sup>giulia.palomba@unime.it,  
<sup>d</sup>pasqualino.corigliano@unime.it, <sup>e</sup>mohamedchairi@cnr.it, <sup>f</sup>guido.dibella@unime.it

\*corresponding author: giulia.palomba@unime.it

**Keywords:** additive manufacturing, bio-composites, natural fiber reinforcement.

**Abstract.** The growing demand for sustainable materials has driven interest in bio-based composites for additive manufacturing (AM). This study explores the feasibility of incorporating untreated coconut fibres into commercial photopolymer resins for stereolithography (SLA). Coconut fibres were extracted, processed, and integrated at varying concentrations into resin formulations, followed by fabrication of ASTM D638 Type IV specimens using a desktop SLA printer and UV post-curing. Mechanical characterization included tensile testing to assess Young's modulus, tensile strength, and elongation at break, complemented by microscopy of fracture surfaces to evaluate fibre dispersion and failure mechanisms. Results indicate good compatibility between coconut fibres and photopolymer resin, with mechanical performance strongly influenced by fibre content. These findings highlight the potential of coconut fibre-reinforced photopolymer composites as sustainable alternatives for AM applications.

## Introduction

The global pursuit of sustainable materials and circular economy principles has intensified research into bio-based composites [1] and their integration in additive manufacturing (AM) [2]. AM offers the potential for sustainable and customizable fabrication with minimal material waste, and within this realm, stereolithography (SLA) is distinguished by its high resolution, surface finish capabilities and dimensional accuracy. This technology is based on the sequential solidification of liquid photopolymeric resins through localized exposure to a focused ultraviolet light source, enabling the fabrication of three-dimensional structures. However, the incorporation of natural fibres into SLA resins remains underexplored due to challenges associated with fibres-resins compatibility, resin rheology, light scattering, cure kinetics, and interfacial adhesion [3].

The integration of lignocellulosic fibres into AM composites offers promising mechanical and environmental benefits. However, numerous challenges still need to be addressed [4]. Among others, Moorthy and Chandran [5], emphasised the critical role of fibre surface treatment and fibre-resin interface chemistry in stereolithography-based natural fibre composites. Prior studies have reported enhanced toughness and biodegradability of composites reinforced with flax, jute or kenaf [6], produced via traditional methodologies. Some promising investigations were performed using natural fibres in different forms in SLA-compatible formulations for AM: it is the case of Rahman et al. [7] who incorporated long-fibres of jute in the middle plane of 3D printed specimens or Wu et al. [8] who used micro-scale bamboo fibres and a vinyl palm oil-based resin to obtain a bio-composite. A recent study from Muller et al. [9] indicated that incorporating short natural fibre fillers or particulates, into photocurable SLA resins can enhance mechanical performance, but results depend on type of loading and treatment. Moderate additions of cotton flakes, miscanthus, walnut, spruce tree, wheat or eggshells improved tensile strength (up to ~22%) while demonstrating excellent matrix-filler interfacial bonding.

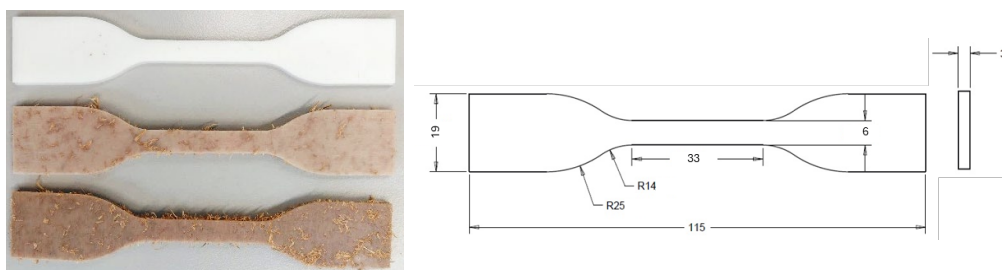
However, few have examined in literature coarse fibres such as coconut (*Cocos nucifera*), which are abundant, cost-effective, with favourable aspect ratio and high lignin content, for AM composites. Some preliminary results of their potential in terms of thermal and dimensional stability improvements on SLA components are provided by Pereyra et al. [10]. Excellent thermal stability, enhanced resistance to degradation and mechanical performance were also reported in Ref. [11], for composites manufactured by traditional techniques with polypropylene and coconut shell particles as filler. A critical parameter in AM bio-composites using coconut fibres is their quantity, as observed by Mosi et al. [12]. They investigated composites produced via fused filament fabrication process using a custom polypropylene filament incorporating coconut fibres. They noted that tensile and flexural strengths reached a peak at  $\sim 2$  wt% fibre, whereas higher fibre content reduced strength due to poor fibre–resin adhesion, as a result of high lignin content in coir fibres which impedes bonding. To boost compatibility, fibres pre-treatments can be performed, as suggested by Rujnić Havstad et al. [13] in a study on moulded composites integrating coconut coir fibres into epoxy resin. They found an optimal combination of alkaline treatments (e.i.  $\text{NaHCO}_3$  soaking) concentration and duration to achieve significantly improved coir/epoxy composite stiffness and strength. Statistical analyses (ANOVA) confirmed these trends, showing fibre content and treatment have significant effects on composite tensile and impact properties.

The current study investigates the feasibility of incorporating untreated and sieved coconut fibres into commercial resins to produce composites via vat photopolymerisation. The aim is to understand the photopolymer-fibre interaction, dispersion challenges, and mechanical performance of printed composite specimens. Through mechanical testing and failure mode analysis, this work contributes new insights into the feasibility of coconut fibre integration in SLA 3D printing and expands the material alternatives for sustainable additive manufacturing.

## Materials and Methods

The composites developed and analysed in the present study use a commercial photosensitive resin as matrix and coconut chopped fibres as reinforcement. The materials examined in this study fall under the category of polymer composites incorporating discontinuous reinforcements, such as particulate matter or short fiber fillers. These types of composites are suited for applications demanding straightforward manufacturing processes along with adequate mechanical strength [9]. The fillers employed in this work were used in their untreated, natural state. They were only extracted, washed in water, dried in an oven and milled before being integrated into a Formlabs White Resin v5, through mechanical stirring to promote homogeneity. In order to investigate the effect of reinforcements/matrix ratio, four different volume concentrations of fibre/resin mixtures were prepared, i.e. 5, 10, 15 and 20%.

Test specimens conforming to ASTM D638 Type IV were fabricated using a commercial desktop SLA printer, i.e. Formlabs 4. Printing was performed with LPU irradiance equal to  $13 \text{ mW/cm}^2$ , model infill exposure of  $8 \text{ mJ/cm}^2$ , exposure of model perimeter and support equal to  $19 \text{ mJ/cm}^2$  and 0.5 s of post-exposure wait time. The printing process was followed by UV post-curing for 5 minutes at  $35^\circ\text{C}$ . Printed specimens and relative geometrical features according to the applied standard are displayed in Figure 1.



**Fig. 1.** Printed specimens at different fibre volume fraction (vol.%) and geometrical features.

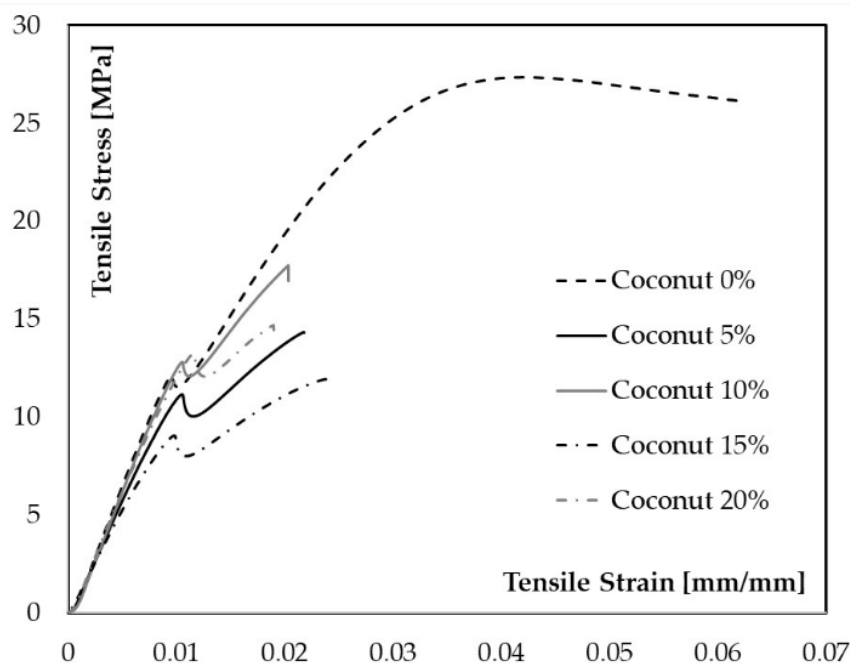
Unreinforced resin specimens, identified as 0% fibres in the following, served as controls. All samples were subjected to tensile testing to evaluate Young's modulus, tensile strength, and elongation at break. Three specimens for each fibre percentage were subjected to tensile tests with a Zwick Roell electromechanical universal testing machine equipped with a 2.5 kN load cell, with a rate of 1 mm/min.

Furthermore, microscopy observations were performed on fracture surfaces to investigate fibre dispersion, resin-fibre adhesion, and crack propagation pathways. The role of fibre content on mechanical performance and fracture modes was systematically compared.

One-way ANOVA and Kruskal–Wallis tests were applied to the tensile test results to assess statistical significance.

## Results and Discussion

Figure 2 shows typical tensile stress–strain curves of SLA-printed specimens produced with neat photopolymer resin (0% coconut fibre) and with increasing coconut fibre contents (5, 10, 15 and 20 % volume).



**Fig. 2.** Stress-strain curves of SLA-printed specimens with different coconut fibre volume fractions (vol.%) subjected to tensile tests.

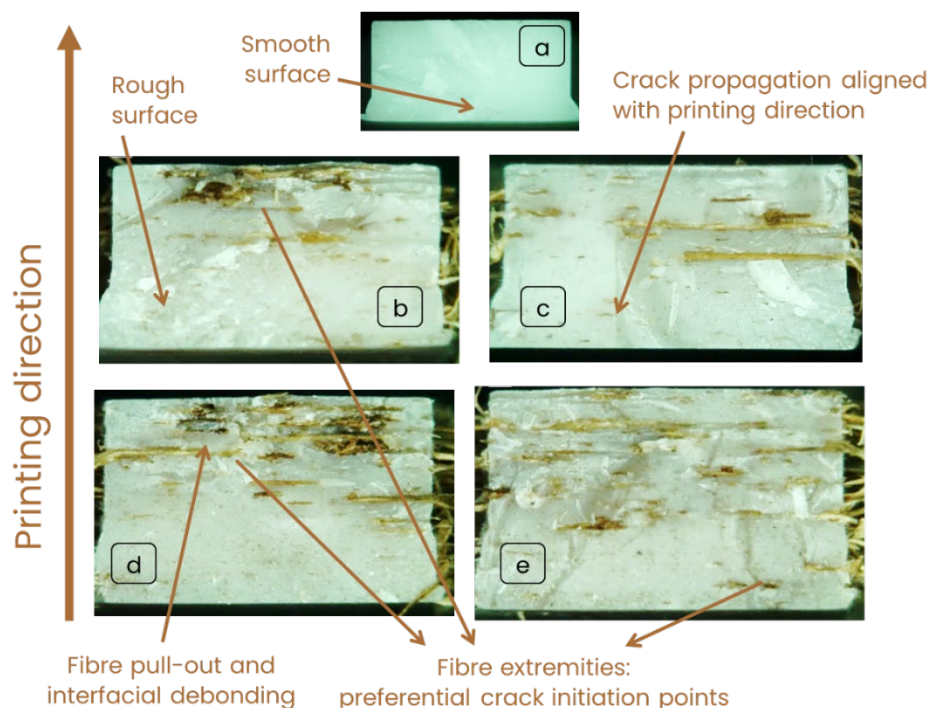
The unreinforced resin exhibits the highest tensile strength and strain at break, reaching a maximum stress of approximately 27 MPa and showing a pronounced nonlinear deformation prior to failure, indicative of post-yield plasticity. This “ductile” response refers specifically to the neat photopolymer resin.

The introduction of coconut fibres significantly modifies the tensile response of the material. The initial slope of the stress–strain curves does not show a clear monotonic change; however, a clear reduction in tensile strength and elongation at break compared to the neat resin is detected. The curves show earlier deviation from linearity and premature failure, in comparison to pure resin. Overall, the fibre-filled specimens exhibit a more predominantly linear-elastic response up to failure, followed by a more abrupt stress drop, consistent with a brittle-like fracture behaviour. The observed response, typical of more brittle materials, suggests the onset of stress concentrations and limited load transfer efficiency at the fibre-matrix interface. This phenomenon may stem from several contributing factors, including fibre agglomeration, increased resin viscosity during printing, and light scattering effects during photopolymerization, which may lead to incomplete curing and the formation of microvoids.

Additionally, the absence of fibre surface treatment likely limits interfacial adhesion, promoting fibre pull-out and crack initiation under tensile loading.

The fracture surfaces of tensile-tested specimens, captured via optical microscopy, are shown in Figure 3 for each fibre content. All samples exhibit characteristics of brittle fracture, as evidenced by clean, planar break surfaces and the absence of significant plastic deformation. This is consistent with the reinforced specimens, where early damage initiation at the fibre-matrix interfaces (e.g., debonding and microcracking) can limit stable plastic deformation of the matrix and promote abrupt failure. In fibre-reinforced specimens (b–e), multiple crack propagation paths aligned with the printing direction are visible, particularly originating from fibre extremities. These discontinuities likely act as stress concentrators and preferential crack initiation points, contributing to the early failure observed in mechanical tests. The pure resin (Figure 3a) shows a smooth and homogeneous fracture surface, while the composite samples display increasing roughness and heterogeneity with fibre content. In samples with higher fibre loadings (15% and 20%, Figure 3 d-e), fibre pull-out and interfacial debonding are evident, suggesting poor fibre-matrix adhesion. This is consistent with the untreated nature of the coconut fibres and may explain the reduced tensile strength observed at higher reinforcement levels. The orientation of visible fibres appears predominantly random, with limited alignment along the stress direction. This may reduce the reinforcing efficiency of the fibres, especially under uniaxial tensile loading.

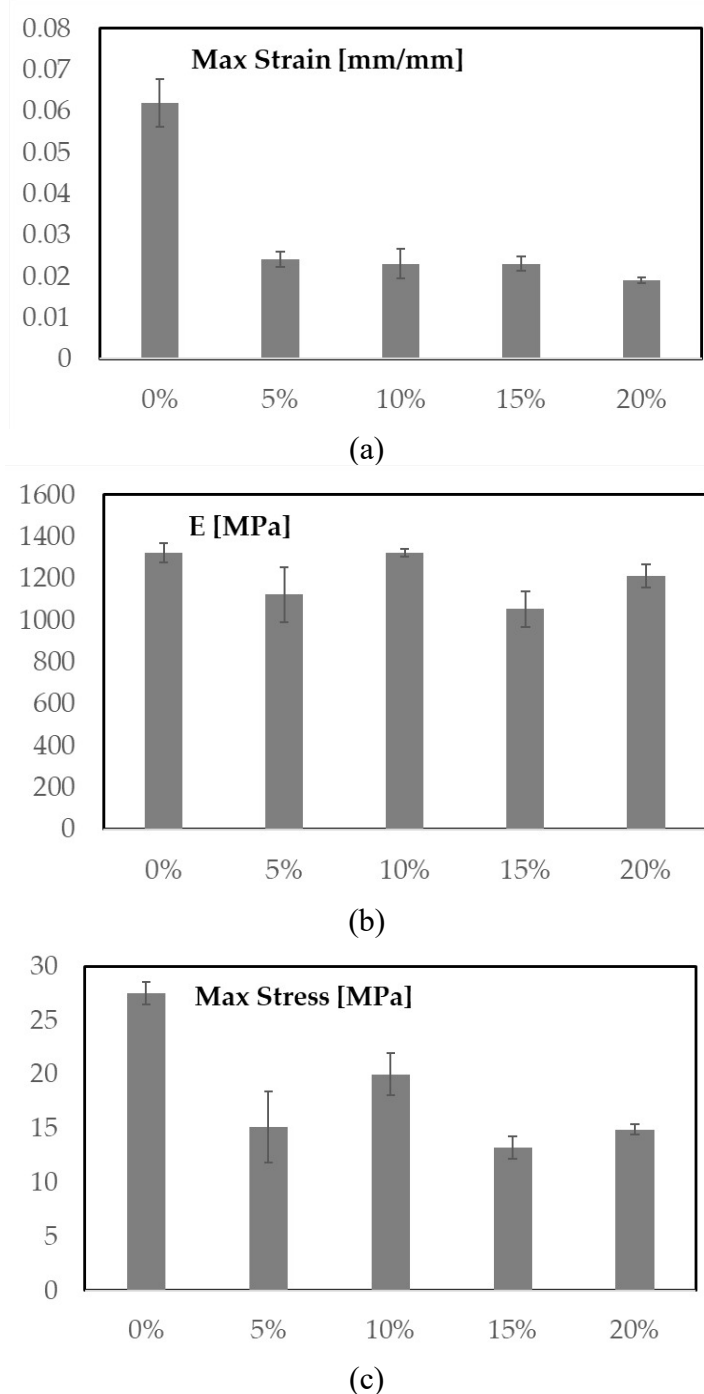
Considering the printing direction indicated in Figure 3, a noticeable geometrical distortion is observed, likely associated with excessive resin adhesion to the build platform and/or local overcuring during the initial layers. Moreover, the fracture surfaces show a higher apparent fibre density in the uppermost printed regions, which is plausibly attributable to phase segregation during the build (e.g., fibre sedimentation/flotation in the vat and/or insufficient homogenisation over time). This evidence supports the hypothesis of a non-uniform fibre distribution throughout the process. The progressive increase in surface roughness and irregularity with fibre volume fraction further suggests process limitations related to increased suspension viscosity and hindered resin recoating, as well as enhanced light scattering/attenuation that can reduce effective UV penetration and curing uniformity. Overall, these observations highlight the need for targeted optimisation of printing parameters (and mixing/homogenisation strategies) in future work.



**Fig. 3.** Fracture surfaces of tested specimens at a) 0%, b) 5%, c) 10%, d) 15%, e) 20% coconut fibres volume content.

Among reinforced specimens, the 10% fibre content shows the best performance in terms of ultimate tensile strength (~17 MPa). At higher fibre loadings (15% and 20%), tensile strength is further reduced, with the lowest values observed within these high-fibre formulations. The 5% content yields intermediate results. The slight slope changes and stress drops may indicate localized fibre pull-out or microcrack initiation under tensile loading. Overall, the results suggest that while small amounts of fibre may be tolerable, excessive fibre loading compromises mechanical integrity in SLA-printed composites, underscoring the importance of optimizing fibre content and interfacial properties for sustainable photopolymer-based composites.

Figure 4 summarises the tensile properties of neat photopolymer resin and coconut fibre-reinforced composites in terms of maximum strain, Young's modulus, and maximum tensile stress as a function of fibre content, reporting the error bars for each volume content.



**Fig. 4.** Results of tensile tests in terms of a) maximum strain b) Young's modulus and c) maximum tensile stress.

The maximum strain at break (Figure 4a) shows a marked decrease with the introduction of coconut. The unreinforced resin exhibits the highest ductility, with a maximum strain of approximately 0.06 mm/mm. Even at the lowest fibre content (5%), the strain at break drops by more than 50%, indicating a strong embrittlement effect induced by the fibres. Further increases in fibre content led to a progressive but less pronounced reduction in ductility, reaching minimum values at 20%. This trend reflects the restriction of polymer chain mobility caused by rigid lignocellulosic fibres and the increased likelihood of stress concentrations at the fibre–matrix interface.

The Young's modulus values (Figure 4b) exhibit a non-monotonic trend with fibre content. Compared to the neat resin, a slight reduction in stiffness is observed at 5% volume content, followed by a recovery and even a marginal increase at 10%. At higher fibre contents (15 and 20%), the modulus decreases again, although remaining within a comparable range. This behaviour suggests a competing effect between the intrinsic stiffness of coconut fibres and microstructural defects such as fibre agglomeration, void formation, and incomplete curing associated with higher filler loadings. The absence of fibre surface treatment likely limits efficient stress transfer, preventing a consistent stiffening effect across all compositions.

The maximum tensile stress (Figure 4c) decreases significantly upon fibre addition. While the neat resin reaches values close to 27–28 MPa, fibre-reinforced specimens show reduced strength, with the lowest values observed at 15% volume fraction. A partial recovery at 10% and 20% may be attributed to improved fibre dispersion at intermediate loadings or statistical variability; however, the overall trend confirms that fibre reinforcement does not enhance tensile strength under the investigated conditions. This reduction is consistent with premature crack initiation at fibre ends, weak interfacial adhesion, and defects introduced during the SLA process.

Overall, the combined results indicate that untreated coconut fibres primarily act as stiffness modifiers rather than effective load-bearing reinforcements in SLA-printed photopolymer composites. The strong reduction in ductility and tensile strength highlights the need for optimised fibre surface treatments, controlled fibre size distribution, and tailored photopolymer formulations to fully exploit the reinforcing potential of natural fibres in vat photopolymerization processes.

To evaluate the statistical significance of the observed mechanical trends, a one-way ANOVA was performed on the tensile test results after verifying normality of the data. The analysis showed that fibre volume fraction has a statistically significant effect on the maximum tensile stress ( $F = 29.82$ ,  $p < 0.001$ ), indicating that coconut fibre content strongly influences tensile strength under the investigated conditions. The model explains a large portion of the variance ( $R^2 = 92.27\%$ ,  $R^2(\text{adj}) = 89.17\%$ ,  $R^2(\text{pred}) = 82.60\%$ ), with a residual standard deviation  $S = 1.85$  MPa.

To further corroborate this outcome without relying on parametric assumptions, a Kruskal–Wallis test was also performed on max Stress. The test confirmed statistically significant differences among groups ( $H = 11.70$ ,  $DF = 4$ ,  $p = 0.020$ ). The average rank values indicate that the 0 vol.% group tends to exhibit the highest tensile strength (Ave Rank = 14.0), followed by 10 vol.% (10.7) and 20 vol.% (7.0), while 5 vol.% (5.7) and especially 15 vol.% (2.7) show the lowest values. Given the small sample size ( $N = 3$  per group), these results should be interpreted with caution; nevertheless, both tests consistently support a statistically significant effect of fibre loading on tensile strength, in agreement with the trends observed in the stress–strain curves.

## Conclusion

The current study presents one of the first experimental investigations into the integration of untreated coconut fibres into photopolymer resins for stereolithography (SLA) 3D printing. The results demonstrate the feasibility of producing fibre-reinforced composites via vat photopolymerization using an abundant, low-cost, and renewable bio-based filler. Although fibre addition led to reduced ductility and tensile strength due to limited interfacial bonding and fibre agglomeration, the modulus was moderately influenced by fibre content, with 10% fibre specimens showing relatively better mechanical balance. Microscopic analysis of the fracture surfaces further confirmed the brittle failure mode and highlighted key microstructural issues such as fibre pull-out, interfacial debonding, and irregular fibre distribution. These phenomena were particularly evident at higher fibre contents, where

poor resin-fibre adhesion and potential sedimentation during printing led to crack initiation and compromised mechanical integrity. Such findings underscore the need for optimized fibre dispersion techniques and surface modification strategies to improve interfacial bonding and ensure uniform reinforcement throughout the printed volume.

These findings offer valuable insights into the use of coarse natural fibres in high-resolution AM processes, expanding the feasible choices of sustainable materials for applications such as eco-friendly prototypes, lightweight non-structural components, or biodegradable consumer products. The work was addressed at laying the groundwork for further developments including fibre surface treatments, resin formulation optimisation, and hybrid reinforcement strategies aimed at improving fibre dispersion and interfacial adhesion. Future research will also explore the impact of fibre orientation, print parameters, and environmental durability, moving toward fully optimized, biodegradable SLA composites for industrial and circular-economy-oriented manufacturing.

### Acknowledgment

The present work is partially funded by European Commission under Grant Agreement n. 101130021 (4TunaTES).

### References

- [1] V. Fiore, T. Scalici, G. Di Bella, and A. Valenza, "A review on basalt fibre and its composites," *Compos B Eng*, vol. 74, pp. 74–94, Jun. 2015, doi: 10.1016/j.compositesb.2014.12.034.
- [2] A. Ganguly, S. Shankar, A. Das, M. Shukla, C. Swaroop, and T. Bhardwaj, "Natural fibre reinforced composites: A review based on additive manufacturing routes and biodegradability perspective," in *Materials Today: Proceedings*, Elsevier Ltd, Jan. 2022, pp. 131–135. doi: 10.1016/j.matpr.2022.02.607.
- [3] F. Ibrahim, D. Mohan, M. S. Sajab, S. B. Bakarudin, and H. Kaco, "Evaluation of the compatibility of organosolv lignin-graphene nanoplatelets with photo-curable polyurethane in stereolithography 3D printing," *Polymers (Basel)*, vol. 11, no. 10, Oct. 2019, doi: 10.3390/polym11101544.
- [4] L. Jiang, X. Peng, and D. Walczyk, "3D printing of biofiber-reinforced composites and their mechanical properties: a review," Jun. 19, 2020, *Emerald Group Holdings Ltd*. doi: 10.1108/RPJ-08-2019-0214.
- [5] S. N. Moorthy J and S. Chandran M, "A comprehensive review on the influence of surface treatment and 3D printing of natural fiber composites," *Compos Interfaces*, pp. 1–36, Jun. 2025, doi: 10.1080/09276440.2025.2525590.
- [6] M. Jawaid and H. P. S. Abdul Khalil, "Cellulosic/synthetic fibre reinforced polymer hybrid composites: A review," Aug. 01, 2011. doi: 10.1016/j.carbpol.2011.04.043.
- [7] M. A. Rahman *et al.*, "Tensile Properties of 3D-Printed Jute-Reinforced Composites via Stereolithography," *Applied Mechanics*, vol. 5, no. 4, pp. 773–785, Dec. 2024, doi: 10.3390/applmech5040043.
- [8] Y. Wu, C. Li, T. Chen, R. Qiu, and W. Liu, "Photo-curing 3D printing of micro-scale bamboo fibers reinforced palm oil-based thermosets composites," *Compos Part A Appl Sci Manuf*, vol. 152, Jan. 2022, doi: 10.1016/j.compositesa.2021.106676.
- [9] M. Müller, J. Urban, J. Svobodová, and R. K. Mishra, "Modification of the Mechanical Properties of Photosensitive Resin by Using Biobased Fillers During Stereolithography (SLA) 3D Printing," *Materials*, vol. 18, no. 12, Jun. 2025, doi: 10.3390/ma18122699.

- 
- [10] I. Pereyra, M. Dehonor-Gómez, J. Mayen, M. A. González-López, and L. E. Lugo-Uribe, “Effect of microcrystalline cellulose and *Cocos nucifera* fibers on the dimensional and thermal stability of a plant-based resin for vat photopolymerization 3D printing,” *MRS Commun*, vol. 15, no. 3, pp. 340–353, 2025, doi: 10.1557/s43579-025-00747-4.
- [11] M. N. Ahmad and M. N. Puasa, “Mechanical and Thermal Properties of Coconut (*Cocos nucifera*)-Reinforced Polypropylene Composite,” *Eng*, vol. 6, no. 11, Nov. 2025, doi: 10.3390/eng6110299.
- [12] G. Mosi, B. W. Ikua, S. K. Kabini, and J. W. Mwangi, “Characterization and Modeling of Mechanical Properties of Additively Manufactured Coconut Fiber-Reinforced Polypropylene Composites,” *Advances in Materials Physics and Chemistry*, vol. 14, no. 06, pp. 95–112, 2024, doi: 10.4236/ampc.2024.146008.
- [13] M. Rujnić Havstad, I. Tucman, B. Krajačić, and A. Pilipović, “Influence of Coir Fibre Preparation on Mechanical Properties of Coir Fibre/Epoxy Resin Composites,” *Journal of Manufacturing and Materials Processing*, vol. 8, no. 6, Dec. 2024, doi: 10.3390/jmmp8060291.