Grenze International Journal of Engineering and Technology, June Issue

An Investigation on the Properties of PLA/TPU Polymeric Blend System as a 3D Printable Material

Suchetha N Raju[1], S H Kameshwari Devi[2], Ajeya K P[3] and K. Prashantha[4]
[1]Department of Polymer Science and Technology, Sri Jayachamarajendra College of Engineering, JSS Science and Technology University, Mysure - 570006
[2-4]ACU-Centre for Research and Innovation, School of Natural Sciences, BGS Institute of Technology, Adichunchanagiri University, B.G. Nagara, Mandya District-571448, Karnataka, India
Email: prashantha.k@gmail.com

***Abstract*—Smart polymer additive manufacturing is a new area of study because of the way these materials structures react to outside stimuli. Shape memory polymers have been printed using Fused Filament Fabrication (FFF) machines using 3D printing concept. Feedstock for FFF machines is commercially available filament. In order to assess their effects on the mechanical qualities, blends of polylactic acid and thermoplastic polyurethanes (TPU) with varied composition ratios were produced using different printing conditions. Research has been carried out on the effects of processing parameters like infill percentage on mechanical behavior of PLA/TPU blends. The results showed that decreasing in TPU blend percentage enhanced the elastic modulus, while increasing the infill percentage tended to greatly increase the tensile strength and elastic modulus. Increasing the infill percentage proved the notable effect of elastic modulus in the 3D printed parts. According to the results obtained, the strain values increased as the infill percentage increased. Overall mechanical studies showed that the composite with 25% TPU was tougher than the clean PLA and could be printed similarly to PLA without losing its properties'.**

***Keywords*— PLA/TPU blends, 3D Printing.**

I. INTRODUCTION

Polylactic acid (PLA) and thermoplastic polyurethane (TPU) are commonly researched polymeric materials for 3D printing because of their unique mechanical and thermal characteristics. PLA is a biodegradable thermoplastic with high rigidity and ease of processing, and it is a material of choice for fused deposition modeling (FDM) [1-2]. Nevertheless, its brittleness restricts its use in flexible or impact-absorbing products [3-4]. TPU, however, is an elastomeric polymer characterized by its resilience and flexibility, and it finds application in cases where toughness and elasticity are desired [5-6]. Mixing PLA with TPU has been extensively studied to enhance impact resistance, flexibility, and mechanical strength while preserving good printability [7-10].

Numerous studies have been conducted on mechanical characteristics of PLA/TPU composites. Rahmatabadi et. al [11] has examined the different blends on PLA-TPU and found improvements in impact resistance, tensile strength and facture toughness. According to Liu et. al. analysis on tailored filament formulation found that the larger TPU percentage results in greater flexibility but decreased overall stiffness [12-13].

Grenze ID: 01.GIJET.11.2.711

He et. al [14] PLA based polyurethanes for its impact on durability and flexibility. Research has also shown that mechanical integrity can be further improved by optimizing processing parameters such as infill density, printing temperature and layer thickness [14].
Effective 3D printing of PLA/TPU blends involves precise regulation of print parameters, filament content, and interlayer bonding. Murillo-Morales et al. [15] explored the impact of lignin as a nucleating agent in PLA/TPU blends, reporting enhanced filament uniformity and print resolution. Liu et al. [12] explored the impact of Fe3O4 reinforcement in magneto-responsive PLA/TPU shape-memory polymers reporting change the mechanical properties and actuation behaviour. Likewise, Suo et al. [18] employed artificial intelligence to optimize print parameters for high-performance PLA/TPU composites. Printability defects like warping, layer bonding, and nozzle blockage have also been investigated, and results showed that adjusting extrusion temperature and print speed greatly enhances surface finish and mechanical properties [19-20].
Thermal stability and degradation are important parameters influencing the longevity of PLA/TPU 3D-printed constructs. Crespo-Miguel et al. [17] investigated thermal and electro-mechanical aging of PLA-based composites, where they discussed the degradation phenomena when subjected to long heating. Kanabenja et al. [23] investigated the influence of hydroxyapatite reinforcement in PLA/TPU blends, where they exhibited greater thermal stability and lower degradation rates. In yet another study, Liu et al. [13] studied the rheological properties of RGO/Ni/PLA/TPU composites, which revealed enhanced thermal resistance and stability under high-temperature use. This suggests that favourable material modifications are able to reinforce the thermal characteristics of PLA/TPU blends for use in industry.
PLA/TPU composites are being extensively investigated for biomedical, automotive, and wearable sensor uses. Ekonomou et al. [19] studied the antimicrobial behavior of PLA/TPU surfaces with Ag and Cu loading, demonstrating promising resistance to foodborne pathogens. In their systematic analysis of 3D-printed polymer composites for wearable electronics, Osman and Lu [21] emphasized the conductivity and flexibility of PLA/TPU blends. The potential uses of electrically conductive polymer composites in smart electronics were investigated by Yan et al. [22] by additive manufacturing. According to the studies, PLA/TPU-based composites are multifunctional and can be tailored for new uses.
The main objectives of research at present are still optimizing blend formulation, processing conditions, and discovering novel applications in the biological and electronic fields. To make PLA/TPU blends more applicable to industries, future studies must be focused on the improvements of electrical conductivity, self-healing, and environmental viability. In line with the general goals of the study, this experimental work seeks to investigate the characteristics of a PLA/TPU polymeric blend system as a 3D printable biopolymer material. The thorough examination of the rheological, mechanical, and thermal characteristics of the PLA/TPU biopolymer blend is performed. The study further needed to identify the 3D printability properties of the blend, considering its proven suitability in biomedical applications like stents, bone grafts, and implants.
Another key objective involves synthesising specific grades of PLA/TPU biopolymer blends with two distinct composition ratios (75/25, 50/50) and varying infill densities (100%, 75%, 50%). The subsequent comparison of their properties aims to identify a superior blend ratio suitable for 3D printing applications, including customizable biodegradable packaging, fit-and-forget biomedical devices, and bone splints.

II. Material and Methodology

A. Research Design

The four stages of the thorough research design, which includes materials and methodology, are covered below.
Stage 1: Blending
The first step in the process was blending Poly lactic acid (PLA) and Thermoplastic Polyurethane (TPU) in some ratio to create a composite material. PLA is a thermoplastic, resource-based, biodegradable polymer with high stiffness and strength but is brittle in some conditions. TPU is an elastomeric polymer with high elasticity and impact resistance as well as high flexibility. The goal was to blend these two polymers in different ratios of 75% PLA / 25% TPU and 50% PLA / 50% TPU resulting in creating a material that would balance PLA's stiffness and TPU's flexibility. Blending the two materials was achieved using a high-shear mixer, which was utilized to blend uniformly the TPU phase into the PLA matrix. Homogeneous blending was necessary because phase separation and low adhesion at the interface would cause the mechanical response of the final composite filament to be negatively impacted.
Stage 2: Filament Extrusion
On completion of blending, the polymer blend was extruded into a filament using a twin-screw extruder. This was an important step to form the blended material in the form of a continuous filament to be used in 3D

printing. The twin-screw extruder was used because of its high mixing performance and efficient processing of polymer blends compared to single-screw extruders. The extruded filament was kept with a uniform diameter of 1.75 mm for a typical desktop Fused Filament Fabrication (FFF) 3D printer. Uniform dimension is an important to facilitate easy feeding and uniform extrusion during printing. Additionally, processing conditions like printing speed, temperature and layer height were optimized to prevent degradation of the polymers and ensure desirable melt flow behavior.

Stage 3: 3D Printing

The extruded filaments were then used in the FFF 3D printer having a 0.4 mm nozzle diameter to 3D print test specimens. FFF is a most popular additive manufacturing process wherein thermoplastic filaments are melted and extruded layer-wise to form objects. To evaluate the structural and mechanical performance of the PLA/TPU blends (PLA75/TPU25, PLA50/TPU50) specimens were printed with three infill densities: 100%, 75%, and 50%. Infill density has direct effects on the mechanical strength, weight, and overall structural integrity of the printed object. A 100% infill density gives a solid structure with maximum strength, while decreasing densities form internal voids, reducing weight and material usage but also affecting mechanical properties. The print parameters, including nozzle temperature, bed temperature, and print speed, were particularly optimized to consider the different viscosities and thermal characteristics of the PLA/TPU blends.

Stage 4: Analysis of test specimens

Once the 3D printing process is completed the test specimens are taken to next stage of examination through various testing. Rheological test were performed to identify the low behavious and viscosity of the polymer blends which define extrusion quality. To evaluate the mechanical characteristics such as strength, stiffness, ductility and energy absorption mechanical tests were performed including tensile and impact testing. Lastly, Fourier Transform Infrared Spectroscopy (FTIR) was used for temperature assessment. Those measurements define how TPU and infill density impacted final material properties and led to further optimization towards practical applications. By following the above systematic testing's, the study is to investigate te possibility of PLA/TPU composites as a viable substitute material for 3D printing. The finding of the experiments can be applied to a range of applications that may required the high strength and shock resistant 3D printing parts such as in medical devices, sports and soft robots.

III. RESULTS AND DISCUSSION

A. Melt Flow Index (MFI)

The melt flow index (MFI) is a key parameter used to evaluate the flowabilty and processability of polymer blends. Table 1 presents the MFI value of the PLA/TPU blends with different compositions.

TABLE I: MELT FLOW INDEX OF PLA/TPU BLENDS

Material Composition	Melt Flow Rate (g/10 min)
PLA75/TPU25	27.73
PLA50/TPU50	32.8

The results indicate that the PLA50/TPU50 blend has a higher MFI than PLA75/TPU25. This suggests that increasing the TPU content in the blend enhances the material's flowability due to reduced viscosity. Since TPU is an elastomeric material, it contributes to improving the processability of the blend. The lower viscosity of the PLA50/TPU50 blend may facilitate better extrusion and layer adhesion during 3D printing.

A bar graph (Fig. 1) comparing MFI values would provide a visual representation of how TPU content affects flowability.

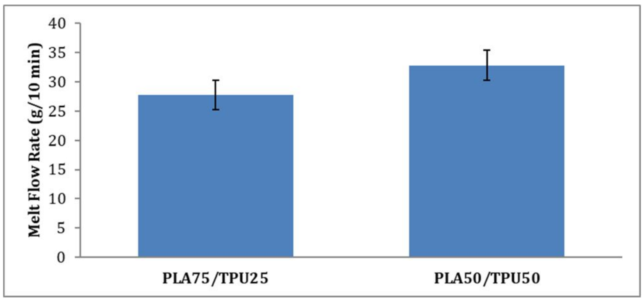

Fig. 1: Melt Flow Index of PLA/TPU Blends

B. Tensile Testing

Tensile tests were conducted on specimens prepared according to ASTM D638 standards to evaluate mechanical properties such as tensile strength, elongation at break, and tensile modulus. The tests were performed using a 10 kN capacity machine with a crosshead speed of 5 mm/min. The results are presented in Table 2.

TABLE II: TENSILE PROPERTIES OF PLA/TPU BLENDS AT DIFFERENT INFILL DENSITIES

Material (Infill %)	Tensile Strength (MPa)	Elongation at Break (%)	Tensile Modulus (MPa)
PLA75/TPU25 (100%)	18.3	12.16	261.3
PLA75/TPU25 (75%)	18.6	13.6	168.3
PLA75/TPU25 (50%)	19.1	15.2	165.2
PLA50/TPU50 (100%)	10.2	12	108.6
PLA50/TPU50 (75%)	11	13.2	71.9
PLA50/TPU50 (50%)	12.3	16.2	63.5

The results indicate that increasing TPU content enhances ductility while decreasing tensile strength and modulus. The PLA75/TPU25 blend exhibits higher tensile strength compared to PLA50/TPU50, which is attributed to the higher proportion of PLA, a rigid thermoplastic. However, with increasing TPU content, the elongation at break increases significantly, indicating improved flexibility.

The bar graphs (Fig. 2 and Fig. 3) showing the variation in tensile strength and elongation at break across different compositions would be useful to highlight these trends.

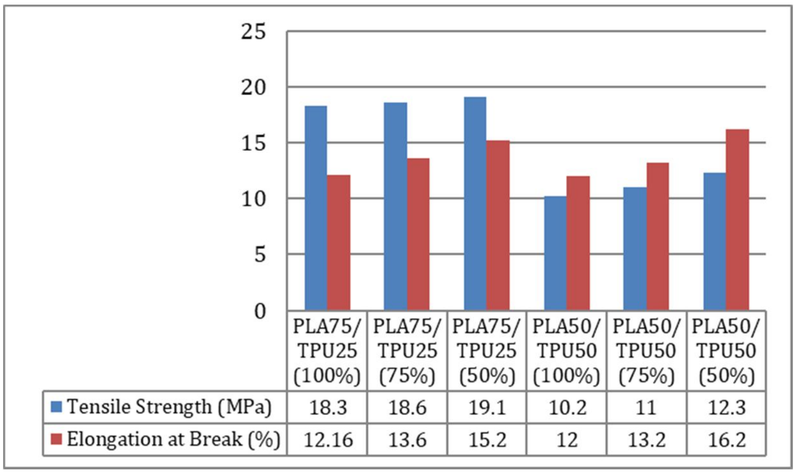

Fig. 2: Variation in tensile strength and elongation PLA/TPU Blends at Different Infill Densities

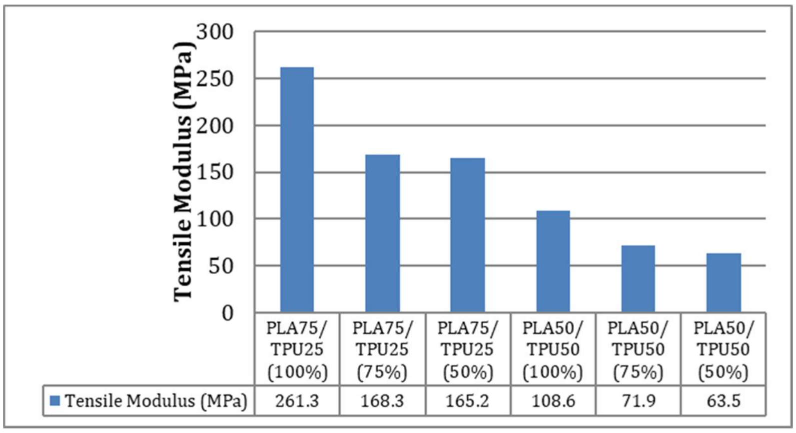

Fig. 3 Variation in Tensile Modulus PLA/TPU Blends at Different Infill Densities

C. Impact Strength

Izod impact tests were conducted as per ASTM D256 standards to assess the impact resistance of the 3D-printed specimens. Table 3 presents the results of impact testing.

TABLE III: IMPACT STRENGTH OF PLA/TPU BLENDS

Material Composition	Energy Absorbed (J)	Impact Strength (J/m²)
PLA75/TPU25	0.1	11.75
PLA50/TPU50	0.15	12.93

The results show that increasing TPU content improves impact strength. The PLA50/TPU50 blend has a higher impact strength (12.93 J/m²) than PLA75/TPU25 (11.75 J/m²), indicating improved toughness.

The presence of TPU enhances energy absorption, reducing brittleness and improving the material's ability to withstand sudden impacts. A bar chart (Fig. 4) comparing impact strength values across compositions would effectively highlight this trend.

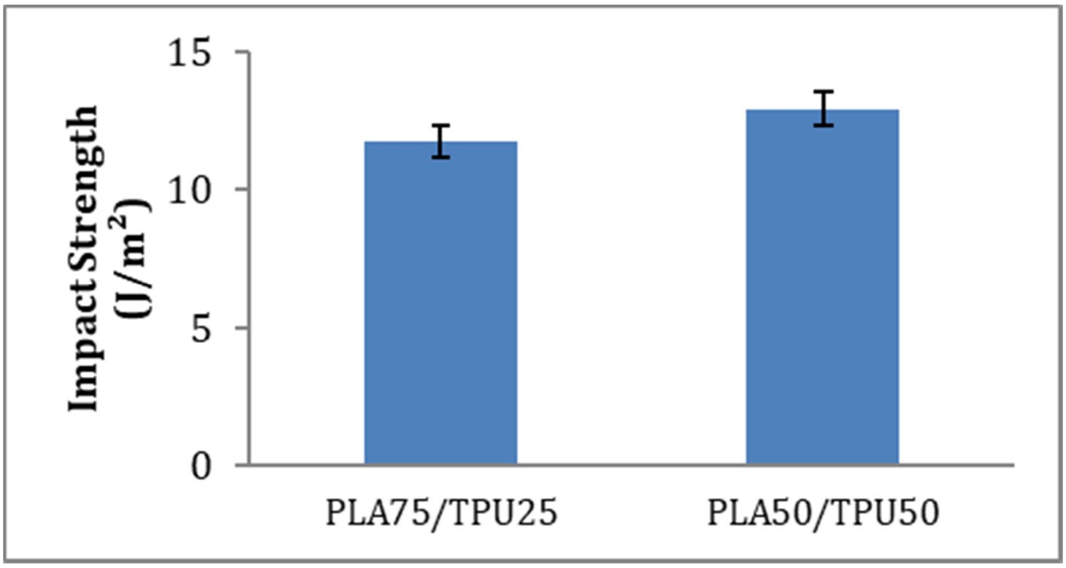

Fig. 4: Impact Strength of PLA/TPU Blends

D. Fourier Transform Infrared Spectroscopy (FTIR)

FTIR analysis was conducted to study the chemical bonding and interactions within the PLA/TPU blends. The results for different compositions are presented in Tables 4 and 5.

TABLE IV: FTIR PEAKS FOR PLA75/TPU25 BLEND

Infill %	C–O (cm⁻¹)	C=O (cm⁻¹)	C–H (cm⁻¹)	N–H (cm⁻¹)	O–H (cm⁻¹)
100%	1110.1	1750.03	2800.12	3330.78	3750.98
75%	1109.23	1750.16	2823.16	3332.45	3752.34
50%	1108.1	1749.67	2846.87	3307.65	3756.87

TABLE V: FTIR PEAKS FOR PLA50/TPU50 BLEND

Infill %	C–O (cm⁻¹)	C=O (cm⁻¹)	C–H (cm⁻¹)	N–H (cm⁻¹)	O–H (cm⁻¹)
100%	1110.92	1752.34	2900.32	3350.67	3750.60
75%	1111.65	1754.78	2916.64	3357.90	3756.98
50%	1113.45	1762.65	2912.32	3356.76	3754.87

The FTIR spectra (Fig.5 and Fig. 6) confirm the presence of characteristic functional groups within the PLA/TPU blends.

The absorption peaks around 1750 cm^{-1} correspond to C=O stretching, indicating ester bond formation, which confirms the compatibility between PLA and TPU.

The peaks at 2800–2900 cm^{-1} correspond to C–H stretching, while the broad absorption at 3300–3750 cm^{-1} is associated with O–H and N–H stretching, confirming the presence of TPU.

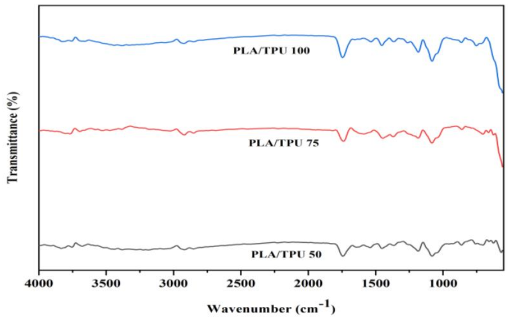

Fig. 5: FTIR Spectra for PLA75/TPU25 Blend

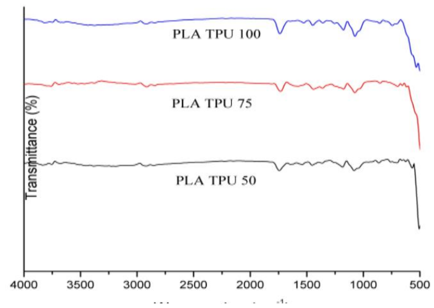

Fig. 6: FTIR Spectra for PLA50/TPU50 Blend

IV. CONCLUSION

This analysis effectively highlights the key trends in PLA/TPU blends. The increase in TPU content leads to improved impact resistance and flexibility, while higher PLA content provides better structural strength. The variations in melt flow index (MFI) indicate that higher TPU content enhances flowability during 3D printing, which can be beneficial for certain manufacturing applications. Additionally, FTIR analysis confirms the chemical interactions between PLA and TPU, supporting the observed mechanical property changes. . Overall mechanical studies showed that the composite with 25% TPU was tougher than the clean PLA and could be printed similarly to PL without losing its properties’.

REFERENCES

[1] S. Campbell, "3D Printing and Its Impact on Society." Technology Innovation Management Review, vol. 4, no. 11, 2014.

[2] C. Hull, "Apparatus for production of three-dimensional objects by stereolithography," U.S. Patent 4575330, Mar. 11, 1986.

[3] S. S. Crump, "Apparatus and method for creating three-dimensional objects," U.S. Patent 5121329, Jun. 9, 1992.

[4] R. Auras et al., "Is Biodegradability a Desirable Attribute for Discarded Solid Waste? Perspectives from a National Landfill Greenhouse Gas Inventory Model." Environmental Science & Technology, vol. 48, no. 1, 2014.

[5] H. Klämpfl et al., "3D Printing with Silicone." Advanced Materials, vol. 29, no. 33, 2017.

[6] Braun, D., Cherdron, H., & Ritter, H. (2001). Polymer synthesis: theory and practice: fundamentals, methods, experiments (pp. 105-110). Heidelberg, Germany::

[7] Springer.https://www.academia.edu/43188724/Polymer_Synthesis_Theory_and_Practice

[8] Qahtani, M. (2019). 3D Printing of Sustainable Poly (Lactic Acid) / TPU Polymeric Blends via Fused Deposition Modeling (Doctoral dissertation, University ofGuelph). https://atrium.lib.uoguelph.ca/items/e80d2e14-1dd9-4418-8bea-3dd69f311c2d

[9] Crawford, R. J., & Martin, P. (2020). Plastics engineering.Butterworth Heinemann.https://shop.elsevier.com/books/plastics-engineering/crawford/978-0-08-100709-9

[10] Yadav, P., Yadav, H., Shah, V. G., Shah, G., & Dhaka, G. (2015). Biomedical biopolymers, their origin and evolution in biomedical sciences: A systematic review. Journal of clinical and diagnostic research: JCDR,9(9),ZE21. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4606363/

[11] Rahmatabadi, D., Ghasemi, I., Baniassadi, M., Abrinia, K., & Baghani, M. (2022). 3D printing of PLA-TPU with different component ratios: Fracture toughness, mechanical properties, and morphology. Journal of Materials Research and Technology,21,3970-3981. https://www.sciencedirect.com/science/article/pii/S2238785422017318

[12] Liu, H., Wang, F., Wu, W., Dong, X., & Sang, L. (2023). 4D printing of mechanically robust PLA/TPU/Fe3O4 magneto-responsive shape memory polymers for smart structures. Composites Part B: Engineering,248,110382. https://www.sciencedirect.com/science/article/abs/pii/S1359836822007557

[13] Liu, S., Wu, H., Chao, B., Fu, W., Deng, K., & Li, Y. (2023). Study on FDM Preparation and Properties of RGO/Ni/PLA/TPU Composite Materials. Journal of Alloys and Compounds,172119. https://www.sciencedirect.com/science/article/abs/pii/S0925838823034229

[14] He, S., Hu, S., Wu, Y., Jin, R., Niu, Z., Wang, R., ... & Zhang, L. (2022). Polyurethanes based on polylactic acid for 3D printing and shape-memoryapplications. Biomacromolecules, 23(10), 4192-4202. https://www.sciencedirect.com/org/science/article/abs/pii/S1525779722007498

[15] Murillo-Morales, G., Sethupathy, S., Zhang, M., Xu, L., Ghaznavi, A., Xu, J., ... & Zhu, D. (2023). Characterization and 3D printing of a biodegradable polylactic acid/thermoplastic polyurethane blend with laccase-modified lignin as a nucleating agent. International Journal of Biological Macromolecules, 236, 123881. https://www.sciencedirect.com/science/article/abs/pii/S014181302300775

[16] Darnal, A., Shahid, Z., Deshpande, H., Kim, J., & Muliana, A. (2023). Tuning mechanical properties of 3D printed composites with PLA: TPU programmable filaments. Composite Structures, 318, 117075. https://www.sciencedirect.com/science/article/abs/pii/S0263822323004191

[17] Crespo-Miguel, J., Garcia-Gonzalez, D., Robles, G., Hossain, M., Martinez-Tarifa, J. M., & Arias, A. (2023). Thermo-electro-mechanical aging and degradation of conductive 3D printed PLA/CB composite. Composite Structures, 316, 116992. https://www.sciencedirect.com/science/article/abs/pii/S0263822323003367

[18] Suo, S., Yang, Y., Wang, Z., & Rao, W. F. (2023). The property palette: A rapid printing of performance-tunable blended polymers guided by artificial neural network. Applied Materials Today, 32, 101837. https://www.sciencedirect.com/science/article/abs/pii/S2352940723001075

[19] Ekonomou, S. I., Soe, S., & Stratakos, A. C. (2023). An explorative study on the antimicrobial effects and mechanical properties of 3D printed PLA and TPU surfaces loaded with Ag and Cu against nosocomial and foodborne pathogens. journal of the mechanical behavior of biomedical materials, 137, 105536. https://www.sciencedirect.com/science/article/pii/S1751616122004416

[20] Bánhegyi, G. (2023). Polymer Compatibility and Interfaces in Extrusion-Based Multicomponent Additive Manufacturing A Mini-Review. Advanced Industrial and Engineering Polymer Research. https://www.sciencedirect.com/science/article/pii/S2542504823000702

[21] Osman, A., & Lu, J. (2023). 3D printing of polymer composites to fabricate wearable sensors: A comprehensive review. Materials Science and Engineering: R: Reports, 154, 100734. https://www.sciencedirect.com/science/article/pii/S0927796X23000207

[22] Yan, Y., Jiang, Y., Ng, E. L. L., Zhang, Y., Owh, C., Wang, F., ... & Chan, B. Q. Y. (2023). Progress and opportunities in additive manufacturing of electrically conductive polymer composites. Materials Today Advances, 17, 100333. https://www.sciencedirect.com/science/article/pii/S2590049822001291

[23] Kanabenja, W., Passarapark, K., Subchokpool, T., Nawaaukkaratharnant, N., Román, A. J., Osswald, T. A., ... & Potiyaraj, P. (2022). 3D printing filaments from plasticized Polyhydroxybutyrate/Polylactic acid blends reinforced with hydroxyapatite. Additive Manufacturing, 59, 103130. https://www.sciencedirect.com/science/article/abs/pii/S221486042200519X

[24] Verma, S., & Verma, V. K. (2022). Shape memory polymers for additive manufacturing: an overview. Materials Today: Proceedings, 57, 2077-2081. https://www.sciencedirect.com/science/article/abs/pii/S2214785321075295