ENHANCING SUSTAINABILITY IN LARGE FORMAT ADDITIVE MANUFACTURING: REAL-TIME RHEOLOGICAL MONITORING AND IN-SITU FLOW CONTROL FOR RECYCLED ABS-GF

Javier Bas Bolufer[1], Pablo Castelló Pedrero[2], César García-Gascón[3], Juan Antonio García-Manrique[4]

Design for Manufacturing Research Institute (IDF). Universitat Politècnica de València, Valencia, Spain,
[1] jababo@upv.edu.es
[2]pabcaspe@upv.edu.es
[3] cegarga3@upv.edu.es
[4]jugarcia@upv.edu.es

Keywords: Large Format Additive Manufacturing, Composites, Circular Economy, Recycling, Material Extrusion (Mex).

Abstract

Large-format additive manufacturing (LFAM) has evolved significantly since its development in the 1980s, transitioning from a tool mostly used for rapid prototyping to a technology capable of producing functional components with high mechanical performance capable of withstanding structurally demanding loads **Error! Reference source not found.**.

Despite the steady growth in the use of these techniques, the development of adjacent processes has not kept pace, creating an urgency to improve key aspects such as print waste management and increasing the average life cycle of manufactured parts while contributing to the circular economy.

Thanks to the use of thermoplastics in LFAM, materials that have been extensively studied, the first advances in material recycling have been achieved in record time. Conventional recycling methods are currently being considered, including mechanical, thermal and chemical processes, with mechanical recycling having the highest percentage of adoption in the industry.

In the absence of a standard for recycling in LFAM, several studies have proposed new methodologies for its implementation in the industry. It has been observed that the mechanical properties of the material vary considerably depending on the technique used. Mohammed et al. (2020) **Error! Reference source not found.** obtained a maximum reduction in tensile strength ranging from 13% to 49%. Walker et al. (2024) **Error! Reference source not found.**reported only an 11% reduction, in addition to a 21% improvement in specific cases. Similarly, Bas et al. (2024) **Error! Reference source not found.**reported an average reduction in tensile strength, varying depending on printing conditions from 0.7% to 14.4%.

As has become apparent, the properties of the recycled material are not consistent, which greatly complicates the establishment of optimal printing parameters. One of the most important aspects is the complex viscosity of the material, which influences both surface quality and dimensional accuracy, characteristics that directly affect interlayer adhesion. Numerous studies have shown that this parameter is the most significant in defining the

mechanical behavior of printed part **Error! Reference source not found.Error! Reference source not found.**.
Therefore, this study proposes the use of capillary rheometry, a widely used test to measure the viscosity of thermoplastics or materials with very high viscosities, in order to evaluate the properties of the material once it has been recycled. Since properties vary after several iterations of recycling and many prints use mixtures of recycled material along with virgin material, there is a need for a tool capable of real-time monitoring of complex viscosity without intermediate testing prior to each print. In this way, the competitive advantages, such as speed and low manufacturing times, inherent to LFAM are maintained.

First, a piston viscometer will be used to measure the viscosity of the composite material (ABS) reinforced with 20% glass fiber, both in its virgin and recycled form. In this way, the characteristic curves of the material will be obtained, which will be used as a reference to calibrate the 3D printer. Once the printer has been calibrated, the values of the extruder screw motor will be used to measure the viscosity in real time, without the need for intermediate tests.

Once the viscosity of the material is controlled in real time, it is feasible to modify the printing parameters in order to improve the mechanical properties. As mentioned above, interlayer adhesion plays a crucial role in the final mechanical outcome of the printed part. Therefore, by knowing the viscosity of the material, it is possible to increase the extrusion flow rate or adjust the extruder temperature to improve such adhesion. In this way, it is possible to implement different recycling methodologies in parallel without affecting the printing results, as this approach allows modification of parameters to suit materials with different properties, without the need for intermediate testing.

Acknowledgement
This work was supported by Generalitat Valencia (GVA) and Spanish Ministry of Science and Innovation. INVEST/2022/131, CIACIF/2021/286, PID2023-151110OB-I00 and CIPROM/2022/3

References

[1] Li, N., Huang, S., Zhang, G., Qin, R., Liu, W., Xiong, H., ... & Blackburn, J. (2019). Progress in additive manufacturing on new materials: A review. Journal of Materials Science & Technology, 35(2), 242-269.
[2] Mohammed, M. I., Das, A., Gomez-Kervin, E., Wilson, D., & Gibson, I. (2020). EcoPrinting: investigating the use of 100% recycled acrylonitrile butadiene styrene (ABS) for additive manufacturing. In 28th Annual International Solid Freeform Fabrication Symposium-An Additive Manufacturing Conference, SFF 2017.
[3] Walker, R., Korey, M., Hubbard, A. M., Clarkson, C. M., Corum, T., Smith, T., ... & Duty, C. (2024). Recycling of CF-ABS machining waste for large format additive manufacturing. Composites Part B: Engineering, 275, 111291.
[4] Bas Bolufer, J. (2024). Development of a methodology for improving the recycling of GF-ABS molds for large format additive manufacturing [Master's thesis, Universidad Politécnica de Valencia]