From Brown Tides to 3D Printers: Fabrication & Characterization of Novel Sargassum-Based Polymer Composite Filaments for 3D Printing

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INTRODUCTION & BACKGROUND

Over the last few years, the volume of floating Sargassum that arrives to the Caribbean beaches has been progressively increasing. More recently in April 2023, 5,000-mile seaweed belt washed up on the shores of many Caribbean islands and some states like Florida and Texas.[1]

¿What is the impact of the Sargassum events?[2]

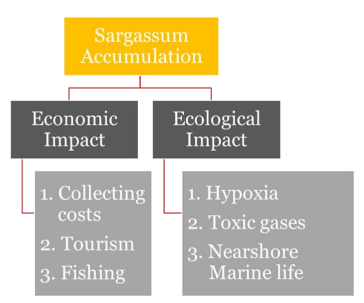

Figure 1. The brown tides impact on the region.

What is driving the huge blooms?[3,4]

- Deforestation increased in the Amazon by 22% during 2020 – 2021 period (beef, forestry, soybean, palm oil, and coffee production)
- With the deforestation of the Amazon, water washes soil and chemical elements into the rivers
- Nitrogen is a nutrient of Sargassum, and its main sources are agriculture, industries and sewage disposal
- Abnormal ocean currents and winds patterns linked to the global climate change
- Occurrence of massive Sahara dust clouds moving over the Atlantic Ocean

Figure 2. Location of the new Sargassum sea

Sustainable & innovative approach

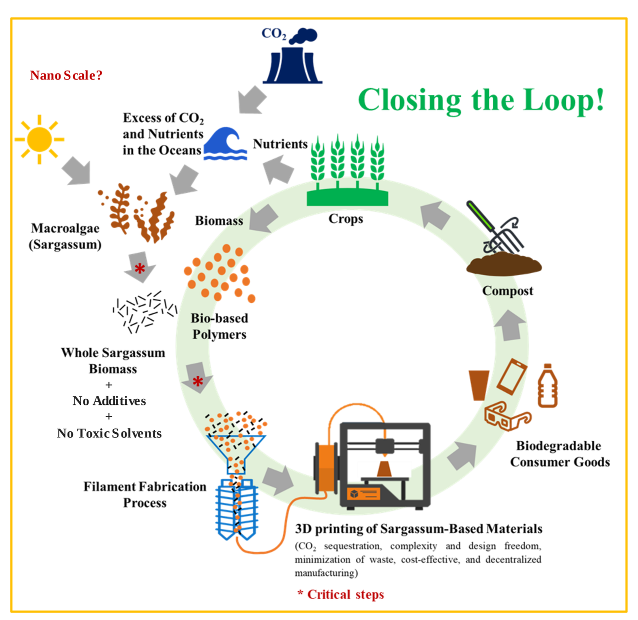

Figure 3. Proposed approach.

Sargassum-based Nanofillers?

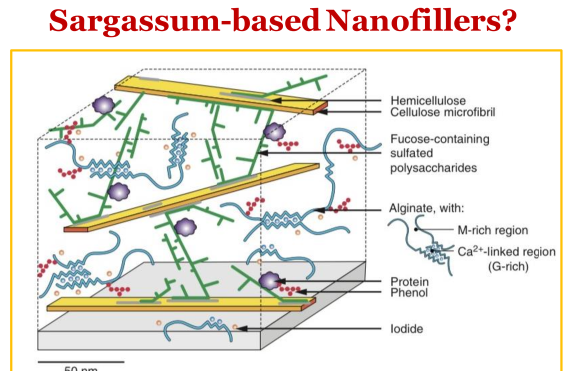

Figure 4. Cell wall model for Sargassum.[5]

PREVIOUS WORK CONTRIBUTIONS

Figure 5. Sargassum powder fabrication process.

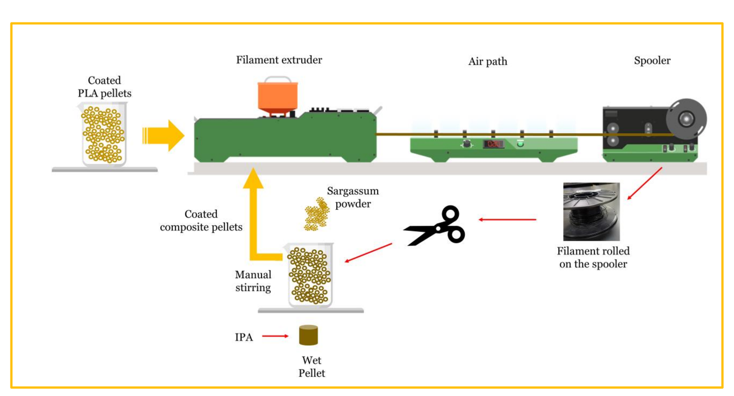

Figure 6. PLA/Sargassum composite filament fabrication process.

Figure 7. Images of some of the fabricated PLA/Sargassum filaments.

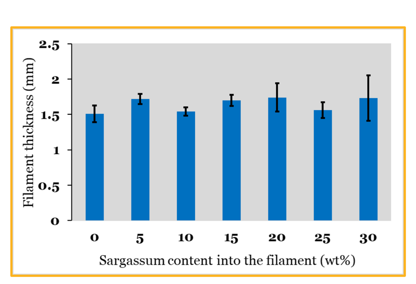

Figure 8. Thickness of the fabricated filaments.

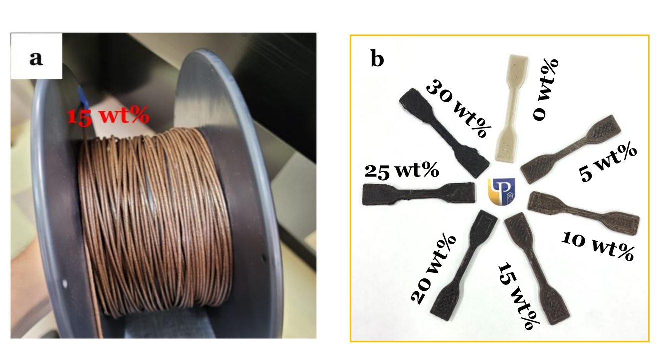

Figure 9. Images of (a) a fabricated filament, (b and c) different dog- bone-shaped specimens for the tensile tests.

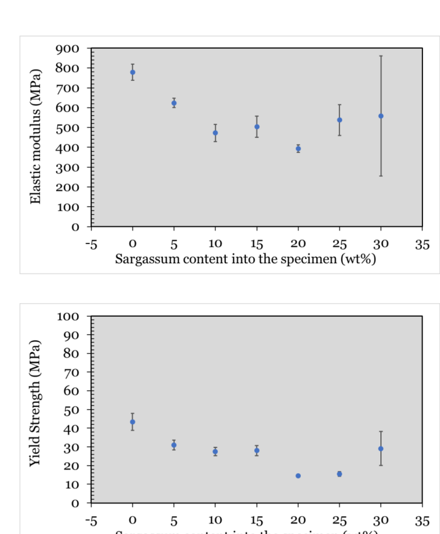

Figure 10. Mechanical properties as a function of Sargassum content (wt%) into the specimen.

Challenge: It has been impossible to fabricate consumer goods with filaments having the higher biomass content (30wt%) since these filaments are very brittle.

It is also necessary to characterize the fabricated powders and composites to understand the relationship between composition, microstructure and properties of the new materials.

New approach: 3D printing of composite pellets

OBJECTIVES

Completion of previous work:

1. Evaluate the particle size, chemical functional groups and thermal properties of the fabricated powders.
2. Study the effect of the Sargassum weight percent (wt%) of the filaments on the microstructure of the fabricated specimens to understand their mechanical properties.
3. Study the effect of the Sargassum weight percent (wt%) on the biodegradability of 3D printed specimens.

New Approach:

4. Stablish the process conditions to fabricate Sargassum-based composite pellets with biomass contents ≥ 30wt%.
5. Stablish the 3D printing conditions to fabricate composite specimens with biomass content ≥ 30wt% using the pellet 3D printing machine.
6. Study the effect of the Sargassum weight percent (wt%) of the pellets on the printability, microstructure, and thermal & mechanical properties of the fabricated polymer composites.
7. Study the effect of the Sargassum weight percent (wt%) of the pellets on the biodegradability of 3D printed specimens.

METHODOLOGY

Completion of previous work:

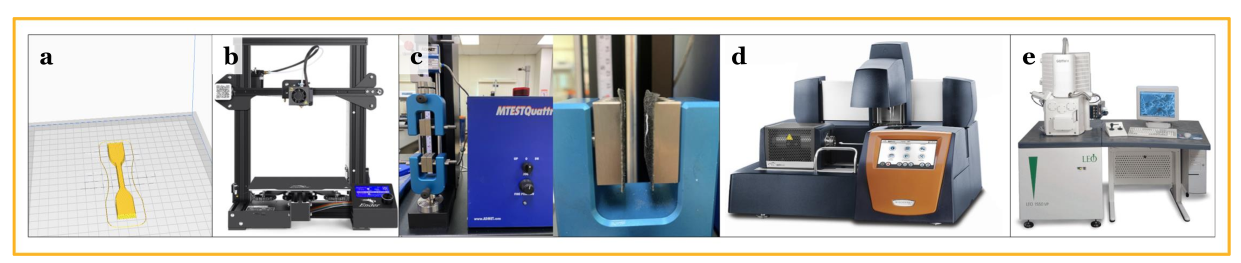

Figure 11. (a) Ultimaker Cura® software showing the created model, (b) Ender-3 Pro 3D Printer from Creality®, (c) tensile test machine with sandpaper attached to the grip surface to avoid slippage, (d) Discovery TA Series TGA and DSC, and (e) LEO scanning electron microscope (SEM) with X-ray for elemental analysis.

Degradation studies were performed via burial tests. In this case, a series of coin-shaped specimens were 3D printed, dried, and weighted before burying them in vases (placed outdoors) containing a suitable amount of homemade compost. 500 mL of water were added onto the surface of each vase weekly to maintain the compost wet. Samples were removed from the compost after 30, 60, 90 and 120 days. After cleaning and drying the samples, these were weighted to calculate the weight losses %.

Figure 12. Images of the burial tests.

New approach:

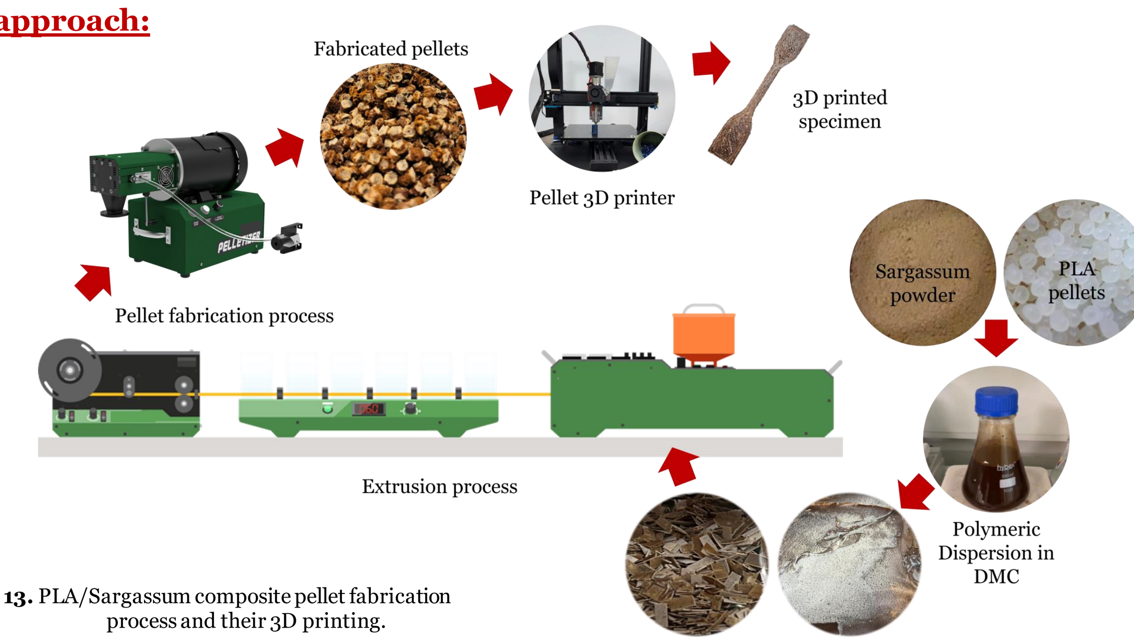

Figure 13. PLA/Sargassum composite pellet fabrication process and their 3D printing.

RESULTS

Powder morphology and size (SEM Analysis)

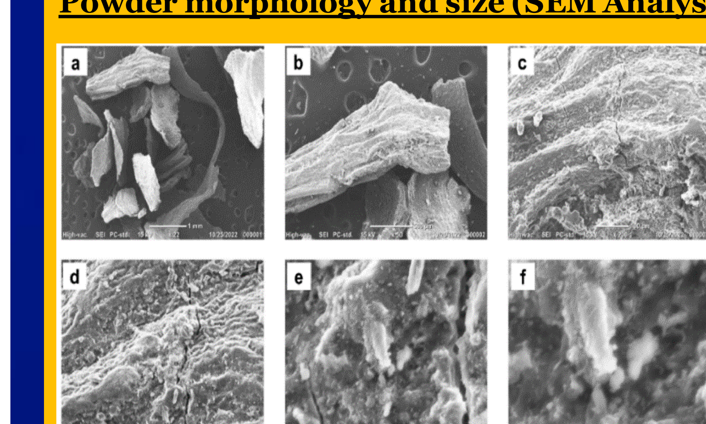

Figure 14. SEM images of dried Sargassum after grinding.

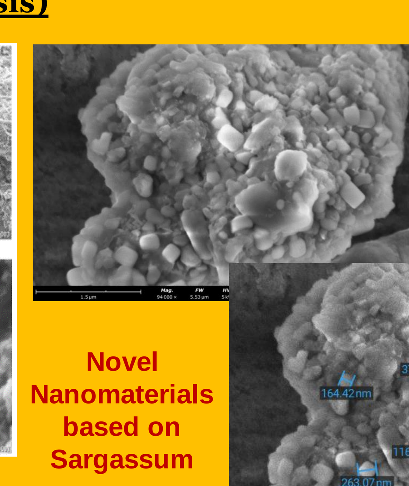

Figure 15. SEM images of dried Sargassum after grinding + ball milling.

Novel Nanomaterials based on Sargassum

Thermal analysis (TGA) for Sargassum powders and filaments

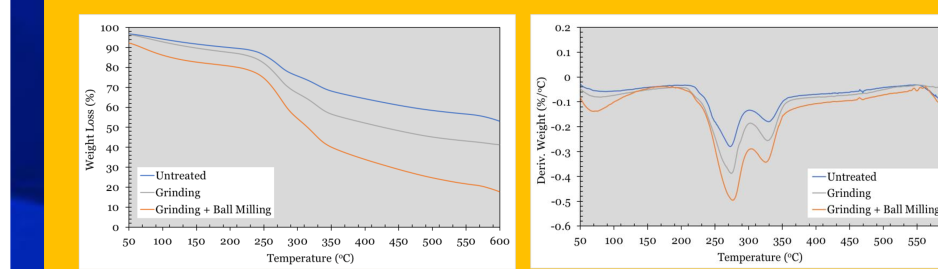

Figure 16. TGA analysis for dried Sargassum, grinded powder, and grinded + ball milled powder.

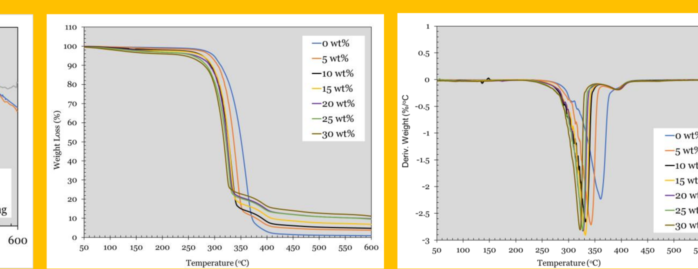

Figure 17. TGA analysis of the composite filaments.

Biodegradability of the 3D printed specimens

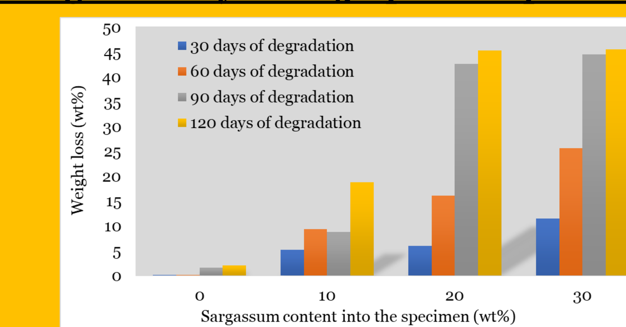

Figure 18. Specimen weight loss (%) as a function of the Sargassum content into the specimen (wt%) at different continuous degradation times (in days).

Microstructure of the 3D printed specimens (SEM analysis)

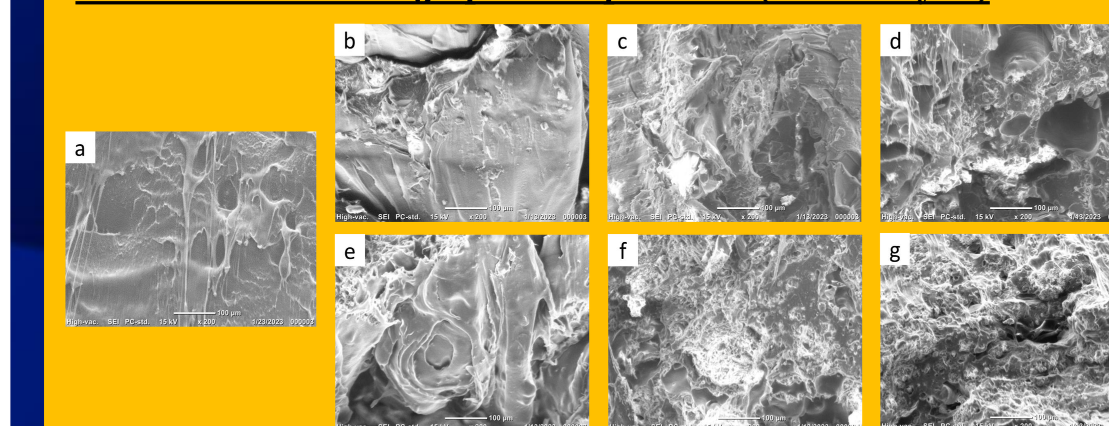

Figure 19. SEM images (fracture views) for 3D printed specimens having Sargassum powder contents of: (a) 0wt%, (b) 5wt%, (c) 10wt%, (d) 15wt%, (e) 20wt%, (f) 25wt%, and (g) 30wt%.

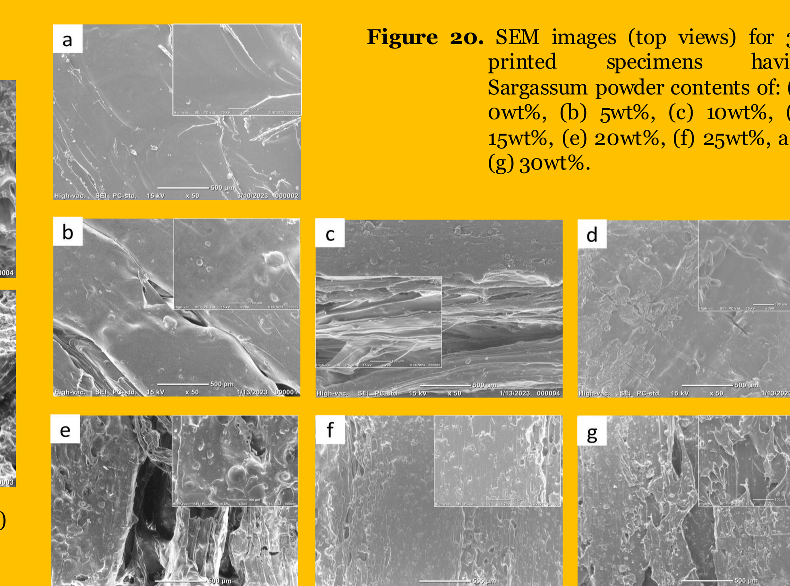

Figure 20. SEM images (top views) for 3D printed specimens having Sargassum powder contents of: (a) 0wt%, (b) 5wt%, (c) 10wt%, (d) 15wt%, (e) 20wt%, (f) 25wt%, and (g) 30wt%.

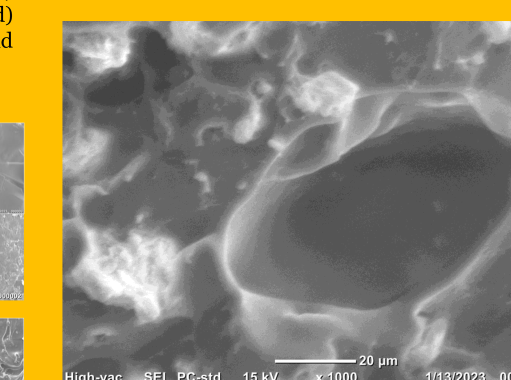

Figure 21. SEM image (fracture view) for 3D printed specimens having Sargassum powder contents of 15wt%.

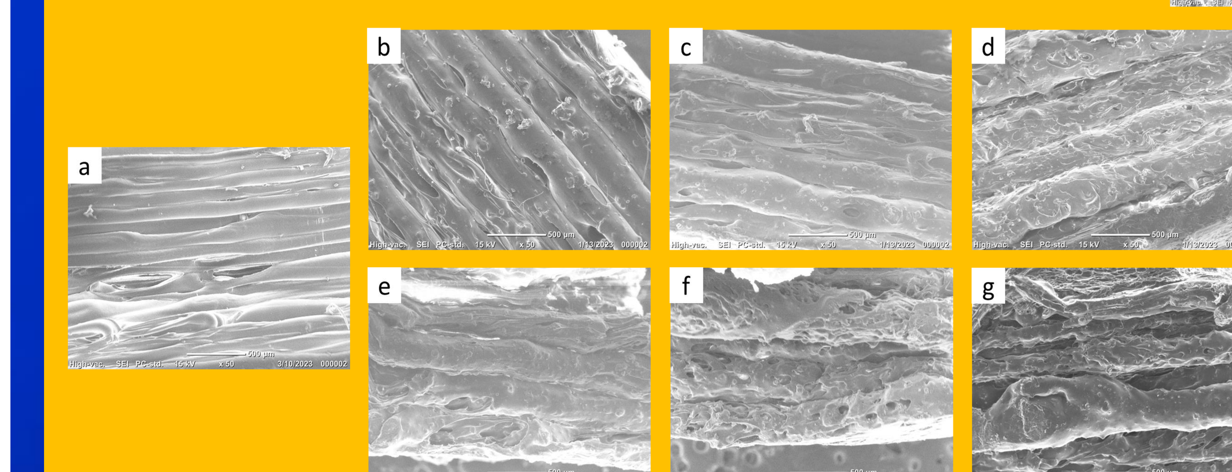

Figure 22. SEM images (side views) for 3D printed specimens having Sargassum powder contents of: (a) 0wt%, (b) 5wt%, (c) 10wt%, (d) 15wt%, (e) 20wt%, (f) 25wt%, and (g) 30wt%.

RESULTS (NEW APPROACH)

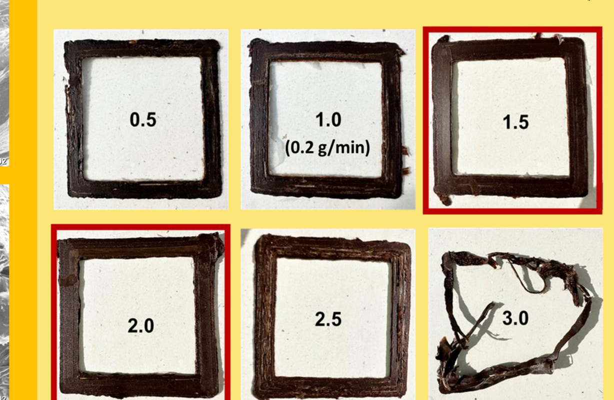

Figure 23. 3D printed composite structures (30wt% Sargassum) fabricated at different flow rates.

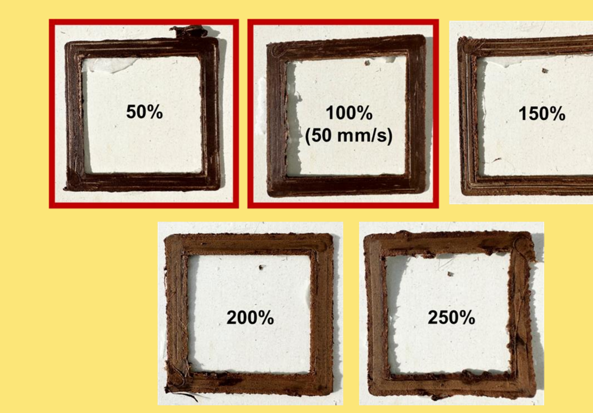

Figure 24. 3D printed composite structures (30wt% Sargassum) fabricated at different printing speeds.

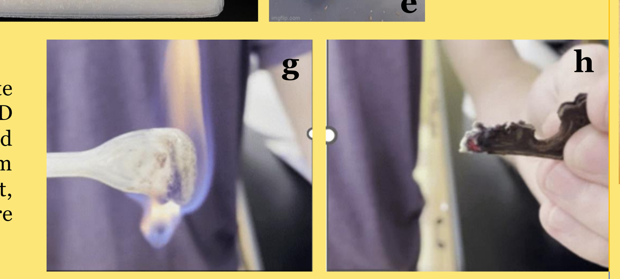

Figure 27. Images of 3D printed parts fabricated with composite pellets having 60wt% Sargassum (SargiWood). (a) 3D printing process of a WAPA key holder, laser engraved logos on 3D printed parts having 60wt% Sargassum (b, c) and 0wt% (d), drilling a 3D printed part, varnish-coated 3D printed part, qualitative fire resistance test of PLA (g) and SargiWood (h).

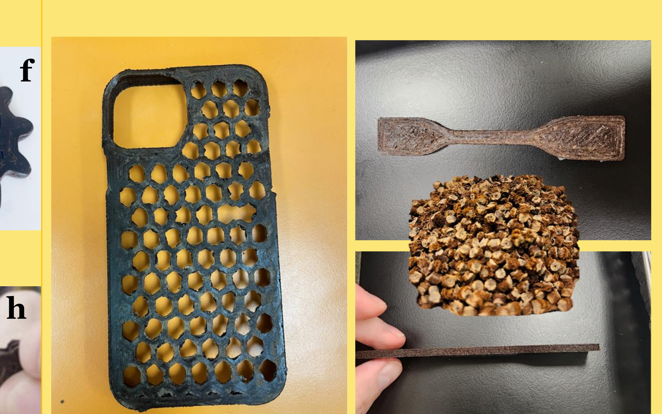

Figure 26. 3D printed part using composite pellets having 30wt% Sargassum

Figure 25. 3D printed stamps for textiles

FUTURE WORK

Fabricate composite especimens using the new approach to determine their mechanical properties and study their microstructures and biodegradability (objectives 6 and 7).

CONCLUSIONS

- Sargassum processed via ball milling exhibited fine particles with nanometric sizes.
- The elastic modulus and yield strength of the 3D printed specimens (using filaments) exhibited a declining trend as the Sargassum content into the PLA polymer matrix increased from 0 to 20wt%. These results are supported by the SEM analysis that shows that the number of defects and surface roughness increases with the biomass content. These defects are usually associated with poor mechanical behaviors.
- When using filaments with higher filler contents, the variability in the elastic modulus was significant, making it difficult to draw precise conclusions. This variability is supported by the inhomogeneities, and defects observed in the microstructure of specimens with high Sargassum contents. The yield strength results followed a similar trend.
- Burial test results suggest that the weight loss (wt%) of the fabricated specimens increases ~9 times as the biomass content increased from 0 to 30wt% (after 120 days).
- It was possible to fabricate 3D printed parts with the obtained composite pellets containing up to 60wt% Sargassum employing the pellet 3D printing machine and the suitable conditions.
- 3D printed parts having 60wt% Sargassum exhibited a wood-like appearance and behaviour (SargiWood).

REFERENCES

RECOMMENDATIONS

- Study the effect of increasing the ball milling time on the sargassum particle sizes and their distribution.
- Study the changes in chemical structure and composition of Sargassum during the powder fabrication process.
- Modify the surface of the Sargassum particles to make this material more compatible with PLA.
- Explore the use of different polymer matrices such as Poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV), Polycaprolactone (PCL), and Acrylonitrile butadiene styrene (ABS).
- Study life cycle environmental impact of these novel 3D printing composite materials.

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