FY22 IRTD Final Report Summary

Project Title: 3D Printed Materials Characterization for Rapid Prototyping and Plant Growth

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Project Description: Low temperature 3D printing (<300 ˚C) technologies have become more affordable and accessible to everyday users and researchers. The result is an increased application of 3D printed plastics into prototyping and experimental hardware. The NASA Space Biology and Space Crop Production team at KSC have taken advantage of this by incorporating low temperature 3D printed thermoplastic filaments into the development of a Controlled Environment (CE) and experiment-unique equipment plant growth hardware as a means of increasing development, and saving time and resources.

As a recently adopted capability, references for characteristics of 3D printed materials (when applied to plant growth systems) are limited to experiments using Polylactic Acid (PLA), or Acrylonitrile Butadiene Styrene (ABS) to create experimental hardware such as NASA's Random Positioning Machine (Zhang, 2021), or the IRTD 2021 Microgreens Root-Shoot Separator Boxes project made from 3D printed PLA and used to harvest microgreens on parabolic flights (Poulet, 2022). As the technology becomes more widely used and additional types of thermoplastic filaments become available, it is vital to understand how these materials behave under relevant scenarios like sanitization, exposure to nutrient solutions, tendency to form biofilms, and the ability to withstand heat and force.

This study compiled a list of off-the-shelf thermoplastic and composite filaments (printed at <300 ˚C nozzle temperature) and ran a series of tests to document properties and characteristics under conditions relevant to CE plant growth. The research team identified and printed 18 filaments in the Plant Processing Area (PPA) in the SSPF. After initial assessment, nine filaments were down selected as the most used industry wide or having potential beneficial properties for space plant biology/crop production use. Characterization of the nine thermoplastic filaments was conducted using printed test specimens in three laboratories (KSC Analysis/Mechanical and Environmental Testing Laboratory for materials testing, KSC Molecular and Microbiological Laboratory for microbial testing, and KSC PPA for plant growth and spectral testing). Materials were scrutinized under various test conditions to assess meeting TRL 6 for plant growth applications.

Project Closeout Summary: Through KSC IRTD funding in 2022, this project brought a list of 18, 3D printed filaments into formal characterization testing to provide a reference for their behaviors under relevant applications. The project format set up a series of tests to expose 3D printed specimens. A total of 1,989 individual 3D printed test specimens were sent across KSC to be scrutinized by three laboratories to fulfill a multidisciplinary assessment of each material TRL.

Testing started with 18 materials. Initially, seed germination assays in the PPA, sample materials were enclosed in petri dishes with lettuce seeds on damp germination paper. No significant impacts on lettuce seed germination were observed in this testing. Next, sample coupons were printed and sent for materials testing to the KSC Analysis/Mechanical and Environmental Testing Laboratory, where they were subjected to 14- and

30-day soak periods in solutions used to provide nutrients to plants or to sanitize hardware before and after use. Following a long soak typical of a 30-day plant growout in Hoagland's solution, 14 materials gained more than 10% of their own mass. This indicated an increased potential for leaching or providing conditions that are not food safe. Materials that exceeded 15% absorption by mass were eliminated from further testing. Based off this result, the team continued with a core list of nine filaments to fulfill Tensile, Flexural, Biofilm formation, and plant growth testing. Those materials were PLA (Raise3D), ABS (Raise3D), PETG (Polyethylene Terephthalate Glycol) (Raise3D), ASA (Acrylonitrile Styrene Acrylate) (Raise3D), PC (Polycarbonate) (Raise3D), TPU (Thermoplastic polyurethane)-95 (Raise3D), PLA Copper (Gizmodorks), PP (Polypropylene) (Braskem), and HIPS (High Impact Polystyrene) (Gizmodorks). Testing also quantified the spectral impact of using different color 3D printed surfaces in a growth chamber. The material used for spectral testing was PLA. Printing employed a standard surface texture representative of all materials.

It was shown through Tensile Testing (ASTM D638-22) that the breaking force of a 3D printed part greatly varied depending on layer orientation. This is common through all materials, and demonstrates that the strength of a 3D printed component can be maximized by layering the material normal to the primary force on the part. Four-point flexural testing (ASTM D790) provided quantities of interest, Flexural modulus, Flexural strength, Flexural stress, and strain at break within a 5% strain limit from each of nine materials.

Biofilm formation testing was conducted in the Molecular and Microbiological Laboratory. Testing completed on specimens from each material showed equal formation on the surface. Additional plant growth testing was conducted in the PPA beyond the initial germination testing.

The final assessment documents that three materials (PLA, ABS, and PC) have reached TRL 6 through extensive testing, and ultimate end-to-end applied use in experimental or testing conditions (flight and ground). TRL 5 materials (ASA, TPU-95, PLA Copper, PP, PETG, and HIPS) have all been successfully applied in Research and Development for crop growth applications and are ready to be applied in formal testing. TRL 4 materials Nylon910, PLA Carbon Fiber, PPA CF, PPA Glass Fiber (GF), NinjaFlex, and P-filament 721 are materials that were able to be printed and tested, but have yet to show data meeting applied requirements. TRL 3 NylonX, Flex TPE-185, and Nylon were unable to be reliably printed to fulfill testing. These results provide researchers with reference for materials to use during plant growth experimentation, and also set a standard for future characterization work applying 3D printing and materials to testing, research, and experimentation.