A System for In-Space Additive Manufacturing Using Recycled Waste

re:3D, Inc

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In-Space Manufacturing via additive techniques is a promising technology for producing structural, repair and crew preference items on demand. A contained recycling system is being developed to utilize discarded materials as the feedstock for 3D printing in microgravity environments for LEO, lunar, or deep space missions.

Introduction

NASA STMD has identified technology shortfalls impacting the agency's Strategic Framework, specifically including topics of Advanced Manufacturing and In-Situ Resource Utilization. There is recognition that manufacturing systems incorporating recycling and reuse will benefit operations from LEO stations to long-duration deep space exploration. Using recycled waste for additive manufacturing is already a non-trivial achievement for terrestrial applications, and the additional challenges of in-space processing and manufacturing will require new avenues of research.

re:3D Inc (Austin, Texas) is an OEM of industrial material extrusion 3D printers, including a line of fused granular fabrication (FGF) printers designed to print directly from recycled polymer granulate. Through a series of NASA SBIR awards, the company has been characterizing a range of waste plastics available for reuse on crewed space missions and is developing a low-SWaP waste-to-print system for use in a microgravity environment.

System Considerations

Feedstock Material
Feedstock is made from thermoplastic waste available or created during normal operations

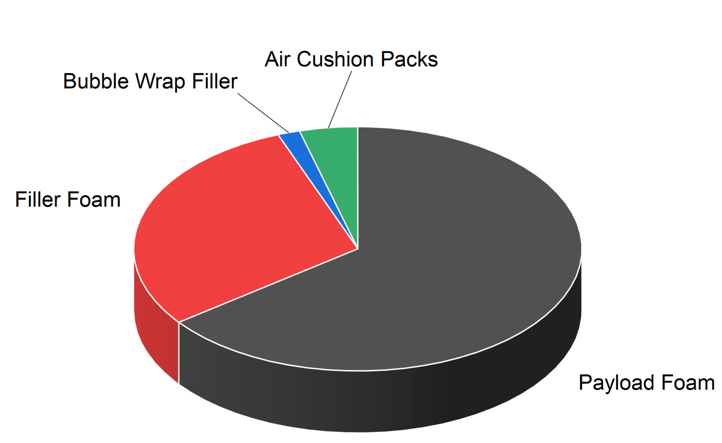
Low-SWaP
System meets the size, power and thermal dissipation limits of an ISS EXPRESS Rack quad MLE

Foreign Object Debris (FOD)
Feedstock is contained at the point of generation and throughout transport and printing

Microgravity
Granulation, feedstock transport and extrusion systems operate independent of gravity

Electrostatic Effects
Triboelectric charging which hinders granulation, transportation or feeding is mitigated

Potential Feedstock Materials

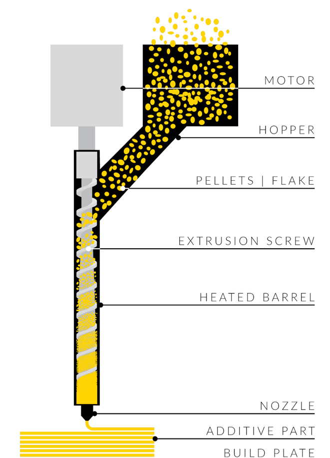


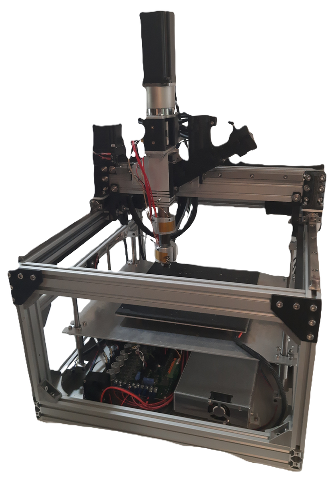
ISS Cargo Stowage Materials (by mass)
Flights HTV9 through SpX-25

Packing and stowage materials are of particular interest for recycling applications. Once past the rigors of launch, much of this bulky protection is no longer needed. These plastics can be easily sorted by type, and they generally remain clean of major contaminants. A survey of ten recent crew and cargo missions to the ISS shows that payload foam constitutes almost 65% of the mass of these protective materials.

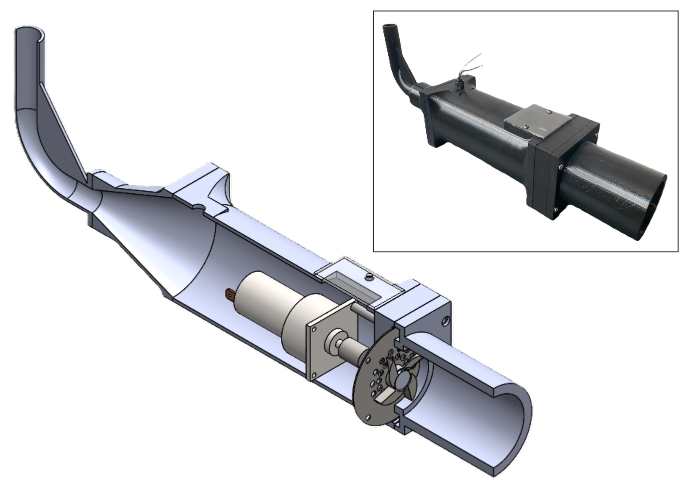
The investigations into candidate waste streams have also included food packaging, disposable crew items and plant science supplies.

Prototyped Hardware





An FGF printer uses polymer pellets or granulate instead of filament as a feedstock. The granulate is fed into a single-screw extruder where the polymer is compressed, heated, melted and forced through a nozzle onto the build surface or lower printed layers. re:3D's industrial FGF printer (the GigabotX) has been formed into a desktop-size unit with significantly lower power requirements.



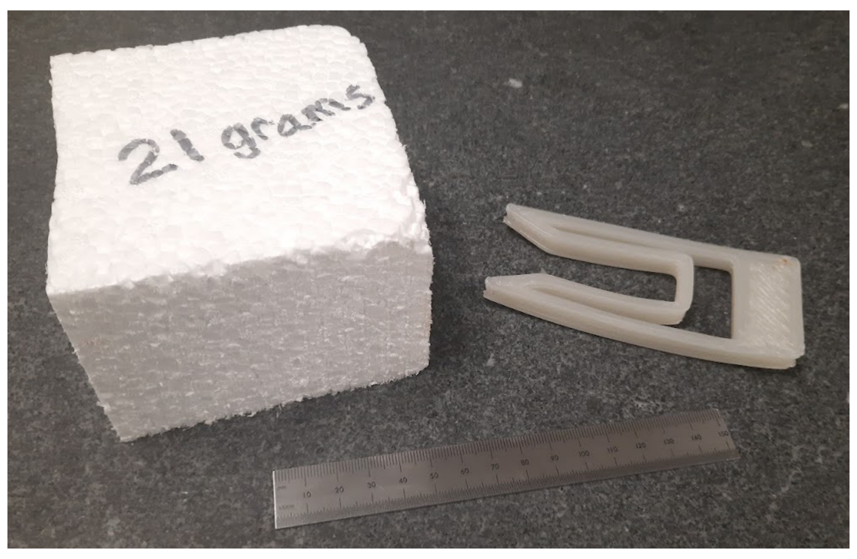
Waste bulk plastic needs to be reduced into granulate on the order of 5mm in size to be used as feedstock in a typical FGF printer. Most commercial granulators rely on gravity to process bulk plastics through one or more sets of cutting knives. Plastics reduced in the prototype low-SWaP granulator are instead mechanically forced against the cutting blade and then pulled into a reservoir via suction.

An eductor (or Venturi pump) uses compressed air to generate suction which will pull the granulate through the reservoir and then entrain it to be conveyed to the printer. An active feed mechanism will exhaust the motive air and force the granulate into the extruder using an auxiliary auger.

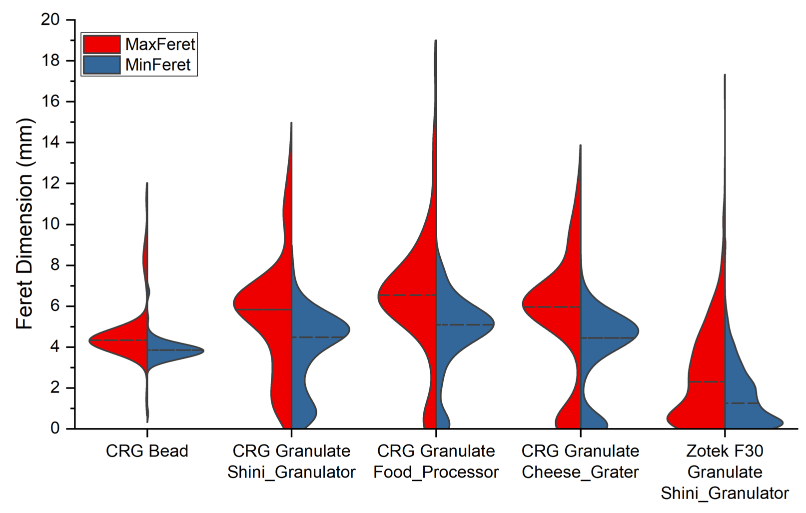
Initial Findings

Using stowage and filler foam as FGF feedstock is attractive. However, the process used in manufacturing the current NASA-approved foams includes a crosslinking step. This prevents the polymer from normal melting once in the foam form. Despite multiple attempts, these foams were found incompatible with recycling through material extrusion 3D printing without additional complex processing steps. However, Cornerstone Research Group (Miamisburg, Ohio) has developed a polyolefin-based foam designed for use as reclaimable packaging for space flight logistics. Research with Marshall Space Flight Center reports that the CRG foam has comparable vibration-damping properties and favorable flammability ratings. Samples of the CRG foam beads and foam blocks are being evaluated by re:3D for use as feedstock in the low-SWaP granulator and FGF printer.

Tensile specimens printed from the CRG foam have mechanical properties which are 70-85% that of comparable molded polymer specimens. The polyolefin polymer is not a stiff plastic, so the printed parts are somewhat flexible and potentially useful for compliant mechanisms or non-rigid fixtures and covers.

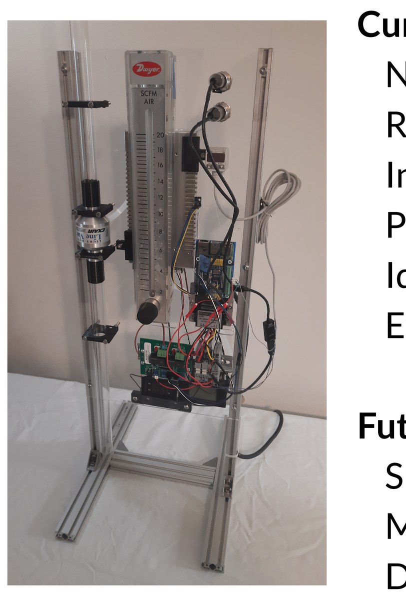


Granulation studies of the CRG block foam have shown that for common mechanical size-reduction approaches (cutting, chopping, shredding, etc.), the average minimum size of the granulate produced is independent of process. The cell-size within the block foam is linked to the size of the precursor foam beads. When granulated, the foam naturally breaks along the interfaces between beads. This provides a consistent granulate size regardless of the mechanical reduction method. The 'natural' size of the CRG granulate is slightly larger than ideal for the re:3D FGF extruder. A smaller precursor bead might improve print-processing, or the feed section of the extruder screw could be modified to accept larger granules.



Granulate Size Distributions

Continuing Work



Currently Underway
- Numerical modeling, testing and validation of the granulate transport system
- Redesigning the extruder's auxiliary feed mechanism to vent the motive air
- Integrating ionized air to mitigate triboelectric static effects
- Packaging the system into a Quad MLE footprint
- Identifying additional use cases and opportunities for recyclate prints
- Evaluating additional waste streams and materials

Future Consideration
- Short duration microgravity tests of the granulate transport system
- Modifications to the CRG foam (smaller precursor beads, use of anti-stat agents)
- Design for future flight testing

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