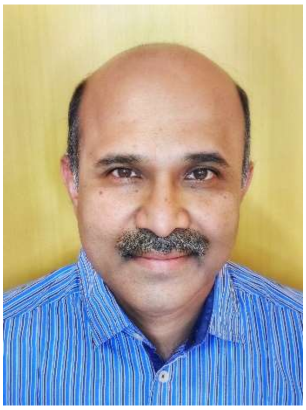
Executive Summary



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1. Title of the Project: 3D Printing of ceramics, metals and composites using aqueous inks

2. Date of Start of the Project: 01 August 2018

3. Aims and Objectives:
   - Scale-up and deployment of technology for 3D printing of waste-based polyolefins
   - Development of a new process for 3D printing of aqueous dispersions, where the dispersions are solidified by freezing
   - Development of a process that combines the ease of FDM 3D printing with the versatility of SLS printing. Design and construction of the necessary hardware to implement this. Development of a 3D printing process for inorganics and metals and appropriate hardware.

4. Significant achievements (from start of project to current)

- Scaled-up laboratory-scale technology for preparation of 3D printing filament based on waste-derived high density polyethylene (HDPE). This process is robust and can be implemented in resource constrained settings such as a garbage collection site. This work resulted in a publication and a technology transfer manual was developed and provided to the business development group at CSIR-National Chemical

Laboratory, Pune. Currently, discussions are ongoing with a social start-up in Pune who is interested in licensing this technology for waste polymer collected and sorted by ragpickers.

- Publication: Gudadhe, A. A.; Bachhar, N.; Kumar, A.; Andrade, P.; Kumaraswamy, G. Three-Dimensional Printing with Waste High Density Polyethylene. *ACS Appl. Polym. Mater.* **2019**, *1*, 3157-3164. [HIGHLIGHTED in ACS Virtual Collection on 3D printing: https://pubs.acs.org/doi/10.1021/acsapm.0c00517]
- Patent filing: Polyolefin composition that can be 3D printed using fused deposition modeling (FDM) technology without warpage (Inventors: Kumaraswamy, G.; Gudadhe, A.)
  Application number (IN): 201711040358
  Granted in Japan: JP6975855B2 (granted on 01/12/2021)
- Outreach whitepaper for packaging industry: Kumaraswamy, G.; Pai, J. Waste to Value: Transforming HDPE Bottles to 3D Printing Filament. 360 Packaging Whitepaper, **2020**. (https://packaging360.in/whitepapers/waste-to-value--transforming-hdpe-bottles-to-3d-printing-filament)
- Developed laboratory scale technology for fused deposition modeling 3D printing of isotactic polypropylene. This work is described in a publication.
- Publication: Bachhar, N.; Gudadhe, A. A.; Kumar, A.; Andrade, P.; Kumaraswamy, G. 3D Printing of Semicrystalline Polypropylene: Towards Eliminating Warpage of Printed Objects. *Bull. Mater. Sci.* **2020**, *43*, 171.
- Book Chapter: Banerjee, S. and Kumaraswamy, G. 3D Printing of Pharmaceuticals for Personalized Medicine. In Engineered Biomaterials: Progress and Prospects, pp. 313-336 (2023), World Scientific. https://doi.org/10.1142/9789811272011_0008
- Developed technology for ink formulation to allow extrusion based 3D printing of inorganic particles. Demonstrated printing of porous hybrid materials and their sintering to form porous inorganic objects.
- This technology also involved hardware modification, to repurpose a low-cost extrusion based printer to enable printing of such inks.

5. Concluding remarks

The key advances in this project include the demonstration of a technology for warpage-free 3D printing of waste derived polymers. This forms the basis of a patent-protected technology that we plan to license to a social start-up working with ragpickers. The other key advance is the development of an extrusion based technology (including hardware modification and ink formulation) and its demonstration. We have printed porous hybrids and sintered these to obtain porous inorganic objects, for the first time, using this technology.