Investigating Design Constraints for Indirect Selective Laser Sintering of Alumina

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Introduction

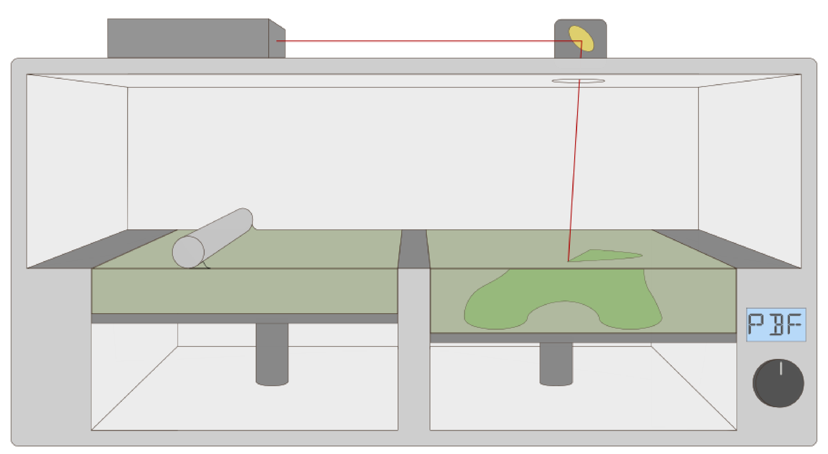
Additive manufacturing (AM) technologies are increasingly being utilized by industries including aerospace, automotive, and medical device. The nuclear industry is following suit, launching research missions to identify how additive manufacturing can streamline innovation in the field. One concern of the nuclear community is how these modern manufacturing techniques could enable a nuclear proliferator. This research investigates the design constraints of ceramic parts fabricated by the indirect selective laser sintering additive manufacturing process. This is of interest because the most common nuclear fuel, uranium oxide (UO_2), is a ceramic. Alumina (Al_2O_3) will be used as a uranium oxide surrogate throughout this work.

Selective Laser Sintering (SLS)

Bulk Material Type:
- Powder

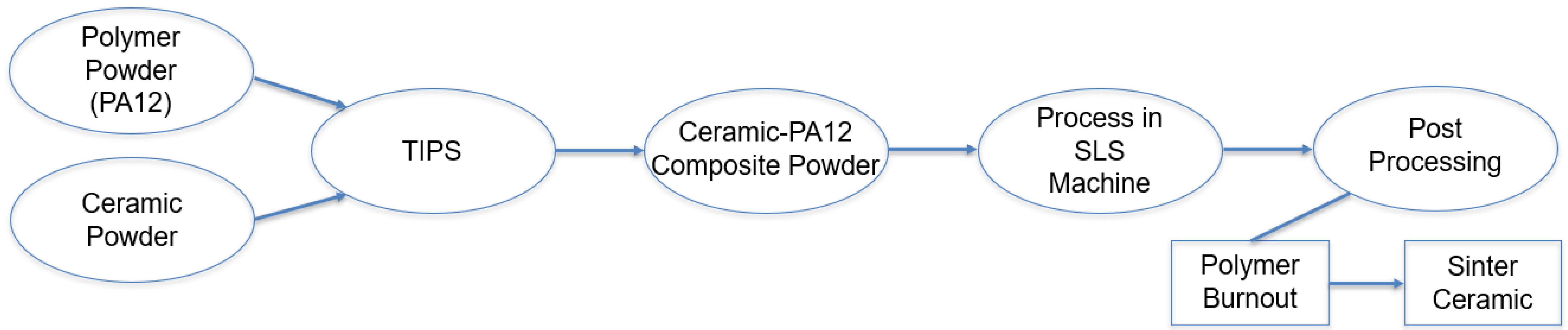
Process Type:
- Laser Melting

Available Materials:
- Metals & Alloys (DMLS)
- Polymers (SLS)
- Ceramics (I-SLS)



Process Advantages	Process Disadvantages
High feature resolution (80-250 µm) Dense parts Great mechanical properties Multi-Material capable	Slower process Expensive compared to other AM Post-processing required for ceramics

Indirect Selective Laser Sintering (I-SLS)



1.) Create polymer/ceramic composite powder for processing in SLS machine. Thermally induced phase separation (TIPS) was chosen for this research

2.) Process composite powder in SLS machine to create complex green body, where sintered polymer is a carrier of the ceramic

3.) Remove sacrificial binder via burnout while also pre-sintering complex ceramic body

4.) Sinter complex ceramic body similarly to traditional ceramic sintering techniques

Thermally Induced Phase Separation (TIPS)

- A method capable of coating ceramics with a spherical polymeric phase [1]
- Employs a polymer and solvent that are insoluble at room temperature, but soluble at elevated temperatures
- When allowed to cool back to room temperature, the phase separation process is initiated
- Cheap but effective alternative to other methods such as spray drying (~$1k vs $100k)
- Provides adequate SLS powder properties to allow for processing in an SLS machine

TIPS equipment setup

Table 1
Densification and flow properties of the raw PA-12 and alumina materials and the obtained alumina polyamide coated particles.

Materials	Hausner ratio – HR[1]	Angle of repose[2]	Spheronization index[3]
Alumina	1,45	50°	0,0611
PA-12	1,15	29°	0,8013
Alumina polyamide coated particles	1,24	33°	0,5607

Notes: 1 - [26]; 2 - [25]; 3 - [30].

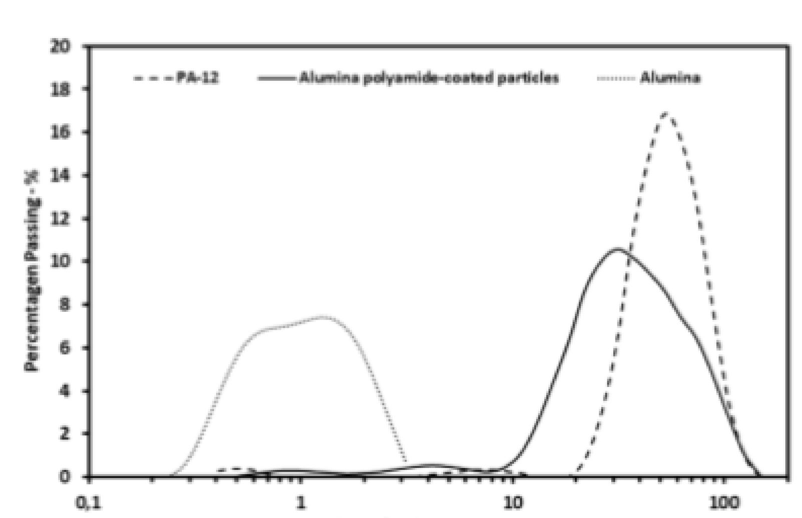
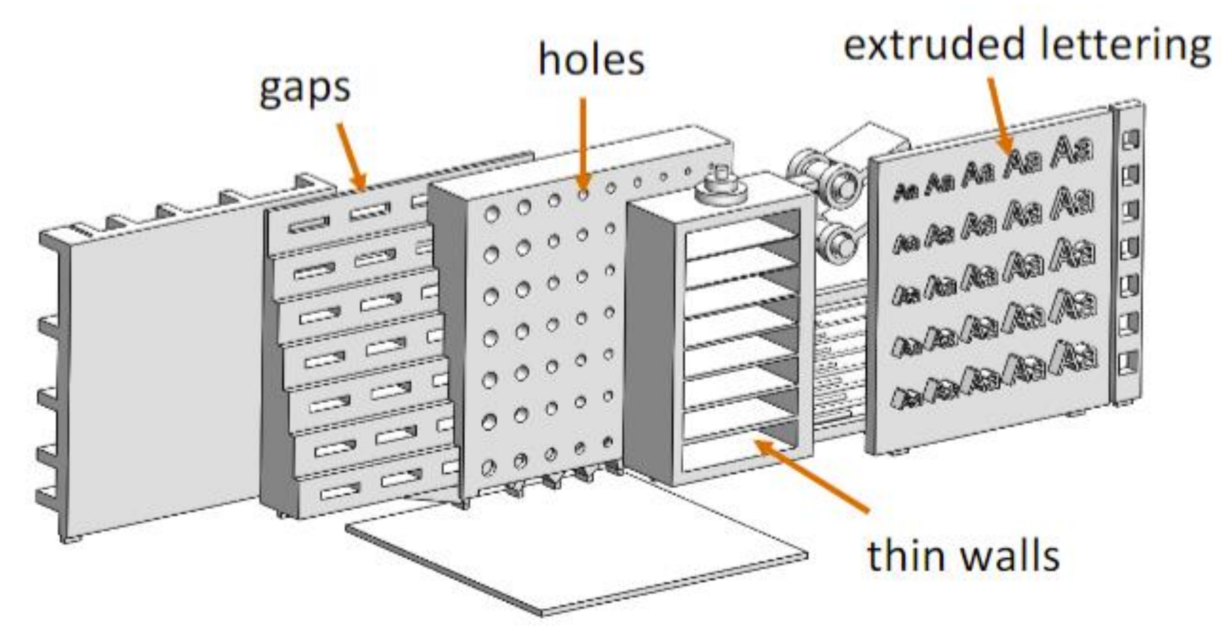


Fig. 4. Granulometric distribution of alumina, PA-12, and the alumina polyamide-coated particles.

I-SLS Design Constraint Investigation

- Will manufacture alumina metrology pieces utilizing the I-SLS process. Metrology piece is comprised of many design features to evaluate resolution feasibility of each feature.
- Will determine what ceramic geometries are feasible to produce using I-SLS. This could help guide complex UO_2 fuel design.



	Holes						
	Hole Diameter (mm)						
Wall Thickness (mm)	2.0	1.8	1.6	1.4	1.2	1.0	0.8
1.0	0.96	0.95	0.94	0.92	0.85	0.76	0.69
2.5	0.91	0.88	0.86	0.78	0.7	0.57	0.41
4.0	0.83	0.8	0.69	0.6	0.49	0.35	0.23
5.5	0.68	0.6	0.55	0.43	0.35	0.24	0.05
7.0	0.58	0.51	0.43	0.36	0.22	0.13	0.04
8.5	0.5	0.43	0.37	0.26	0.16	0.07	0.04
10.0	0.5	0.4	0.32	0.17	0.08	0.06	0.04

Example metrology piece (left) and design constraint chart (right) [2]

References

[1] Shahzad, K., Deckers, J., Boury, S., Neirinck, B., Kruth, J., & Vleugels, J. (2012). Preparation and indirect selective laser sintering of alumina/PA microspheres. *Ceramics International*, *38*(2), 1241–1247. https://doi.org/10.1016/j.ceramint.2011.08.055

[2] Seepersad, Carolyn C. "Embodiment Design: Design Guidance for SLS." ME397: Additive Manufacturing Lecture. ME397: Additive Manufacturing Lecture, 14 Apr. 2020, Austin.