3D PRINTING: SOLVENT TRANSPORT IN A POWDER BED

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Project Overview

Issue and Opportunity

Metal 3D printing can create high quality functional parts at high volumes. The current process is production limited by the mass transport of solvent through the powder bed. Mass transport is a function of diffusion, time, and temperature.

HP Jet Fusion 3D Printing Process

1. Powder Spreading - Thin powder layer is placed into the building unit
2. Printing - Thin layer of ink is printed onto the location of the desired part
   a. Ink contains binding agent, solvent, and water and spreads until parts have been completed
3. Baking - Building unit is removed from printer and heated for solvent removal
4. Decaking - Unprinted powder is removed and used for later printings

Figure 1: HP Jet Fusion Series printer

Objectives

Characterize mass transport of solvent through a powder bed by modeling transport behavior using an estimated experimental diffusion coefficient, D_{AB}. Use transport behavior model to explore viable methods of increasing mass transport rate in order to increase part quality and reduce production time.

Figure 2: Microscopic scale picture of solvent within the powder pores.

Mass Transfer Characterization

The mass transfer phenomena of focus is diffusion. The Arnold Cell Diffusion model was used to characterize the mass transport of solvent, with the assumption that the diffusion path length changes a small amount over a long period of time, Eq. 1. Using this model, the pathlength, Z, was measured over time, t. The solvent diffusion coefficient (D_{AB}) was estimated to be 0.02 cm^2/s ± 0.01 cm^2/s using the slope.

$$t - t_0 = \frac{\rho_{A,L}\, y_{B,lm}}{C\, M_A\, D_{AB}(y_{A,1} - y_{A,2})}\left(\frac{Z^2 - Z_0^2}{2}\right)$$

Equation 1: Arnold Diffusion Equation

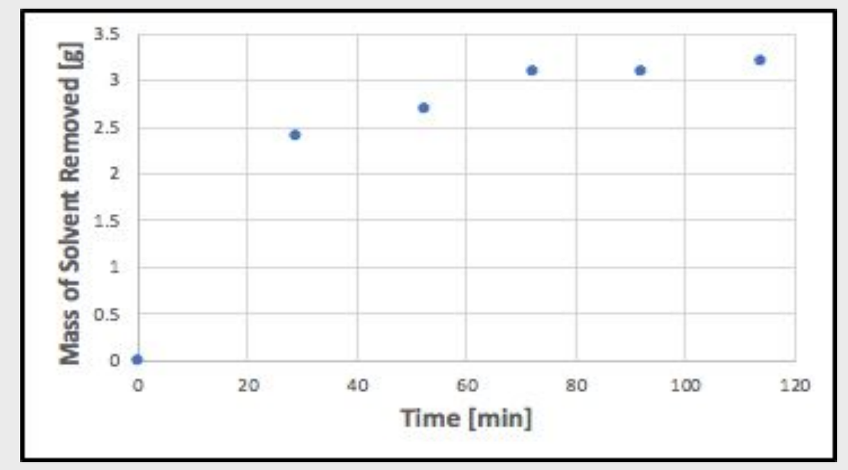

Figure 3: The mass of solvent removed over time at 140°C when loaded with 6.7 grams of solvent.

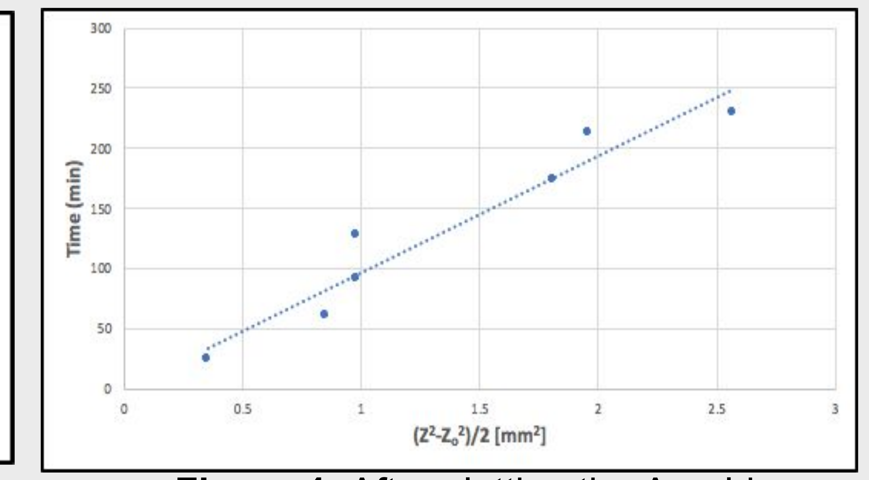

Figure 4: After plotting the Arnold Model pathlength vs time from Eq. 1, the Diffusion Coefficient, D_{AB}, was able to be estimated from the slope to be 0.01 cm^2/s .

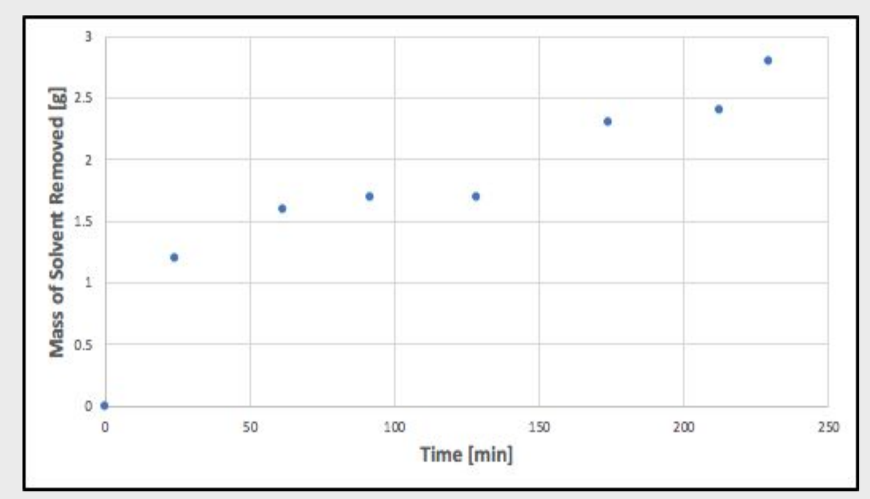

Figure 5: The mass of solvent removed over time at 140°C when loaded with 6.4 grams of solvent.

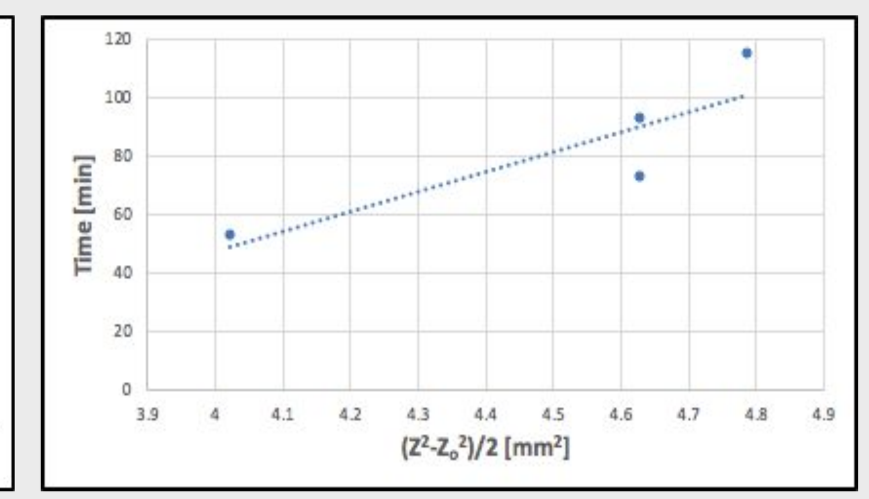

Figure 6: After plotting the Arnold Model pathlength vs time from Eq. 1, the Diffusion Coefficient, D_{AB}, was able to be estimated from the slope to be 0.02 cm^2/s .

Solvent Transport Model

The solvent transport model was generated assuming the transport within the powder bed can be modeled as a semi-infinite medium with a constant source and transient sink by using the error function.

$$C_A = \left(1 - \operatorname{erf}\left(\frac{z}{2\sqrt{D_{AB}t}}\right)\right) \cdot (C_{AS} - C_{A0})$$

Equation 2: Semi-Infinite Medium Transient Diffusion Equation

The error function equation was used to determine the change in concentration as a function of position in order to estimate the flux, Eq. 2. The flux equation, Eq. 3, was integrated as a function of time in order to estimate the mass of solvent at position z, Eq. 4.

$$N_A = -D_{AB}\frac{dC_A}{dz}$$

Equation 3: Flux equation using the diffusion coefficient and the change in concentration as a function of position

$$m_{A,z} = SC_{AS}\left(\frac{2\sqrt{D_{AB}t}}{3\sqrt{\pi}\cdot\sqrt[3]{D_{AB}}}\left(\sqrt{D_{AB}}\,e^{\frac{-z^2}{D_{AB}t}}(D_{AB}t - 2z^2) - \frac{2\sqrt{\pi}z^3\operatorname{erf}\left(\frac{z}{\sqrt{D_{AB}t}}\right)}{\sqrt{t}}\right)\right)$$

Equation 4: The resulting equation models the mass transport of solvent as a function of time.

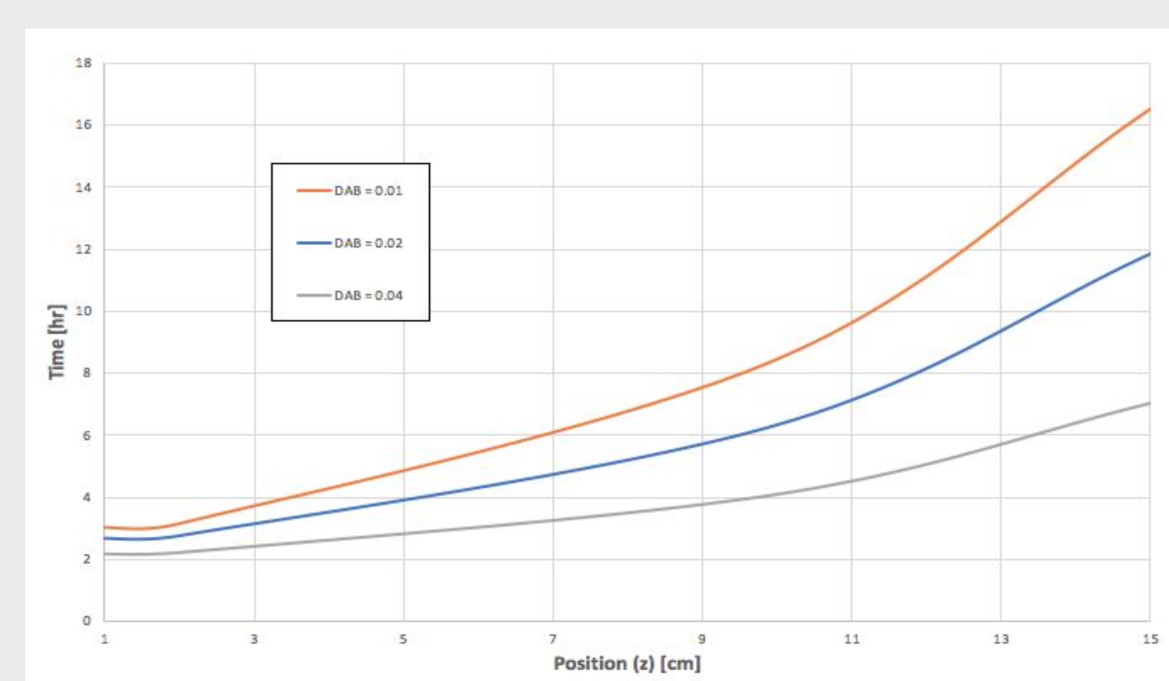

Figure 7: The time required for 6.4 g of solvent to be completely removed at a designated position away from the part, z, at diffusion coefficients of 0.01, 0.02, and 0.04 cm^2/s.

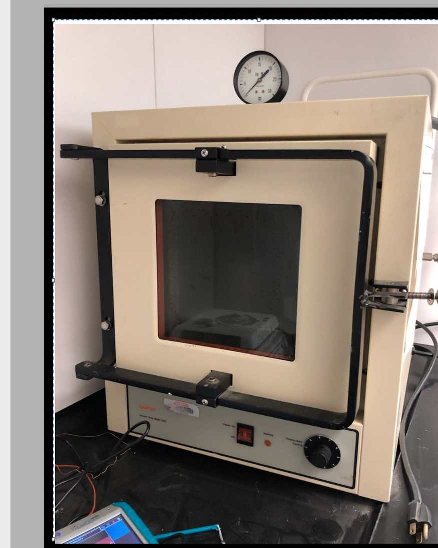

Figure 8: Vacuum oven that was used to conduct flux experiments for solvent transport. The vacuum oven was set at 140-150°C. Both the solvent and powder were preheated before mixing and experimentation

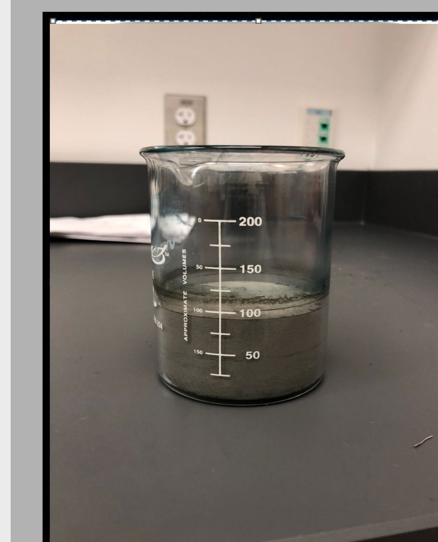

Figure 9: Powder and solvent were added to a beaker and the mass was recorded. The mixture was taken out and the mass was measured at 20-30 minute intervals for up to 4 hours.

Future Work

- Conduct experiments using solvent that does not contain water
- Compare model results to physical experimentation
- Work with HP research team to enhance model and apply to current 3D printing process

Acknowledgements

HP - Project Sponsor

Dr. Jason Hower, Project Mentor - Thank you for the opportunity to work with HP on this project, for providing project guidance, and providing materials for the team to be successful.

OSU

Dr. Phil Harding, Project Mentor - Thank you for providing insight each week and making us better engineers

John Cochran - Thank you for lab access and general lab assistance

Andy Brickman - Thank you for lab access and assisting with equipment setup/issues

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