Part Smoothing Models for Additive Manufactured Titanium

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INTRODUCTION

Additive manufacturing (AM) is used to manufacture titanium parts through a process called laser powder bed fusion (LPBF) where powdered metal is fused together one layer at a time using a laser beam energy source. However, parts made using LPBF have rough surfaces and can be difficult to machine conventionally due to complex geometries. Instead, a chemical milling process is used to evenly remove material at all surfaces to smooth the part. This process can be unpredictable and it is difficult to observe this process as it occurs due to the acidic environment that is not compatible with measurement equipment.

PROPOSED SOLUTION

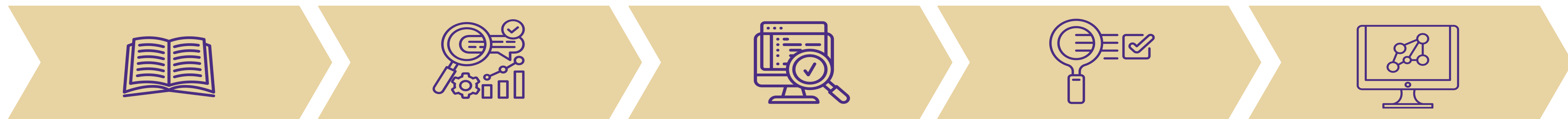
Create a predictive model to simulate the chemical milling process. This solution reduces the time and cost associated with printing real parts, chemically milling them, and measuring the final results in order to get parts to a producible state. A finite element method (FEM) software known as COMSOL was used to build the model. We decided to use this software because of its wide range of built-in physics packages.

OBJECTIVES

- Produce converging predictive model
- Identify important etching parameters
- Test how varying these parameters will change etch rate
- Provide documentation for replicating the final model

DEVELOPMENT

- We started from the COMSOL model produced by last year's Capstone team which simulated the liquid flow and gas entrapment resulting from a constant etching reaction rate.
- More details were added to the model iteratively, including the coupling of reaction rate and gas generation to the simulated acid concentration and temperature. At each stage, we checked for qualitative accuracy based on literature values and mentor expertise.
- Various process conditions including etchant concentration and part geometry were tested.



Learn COMSOL
- Literature Review
- COMSOL practice
- Analyze previous capstone group's project

Qualitative Accuracy
- Add parameters
- Set boundary conditions
- Test for continuity

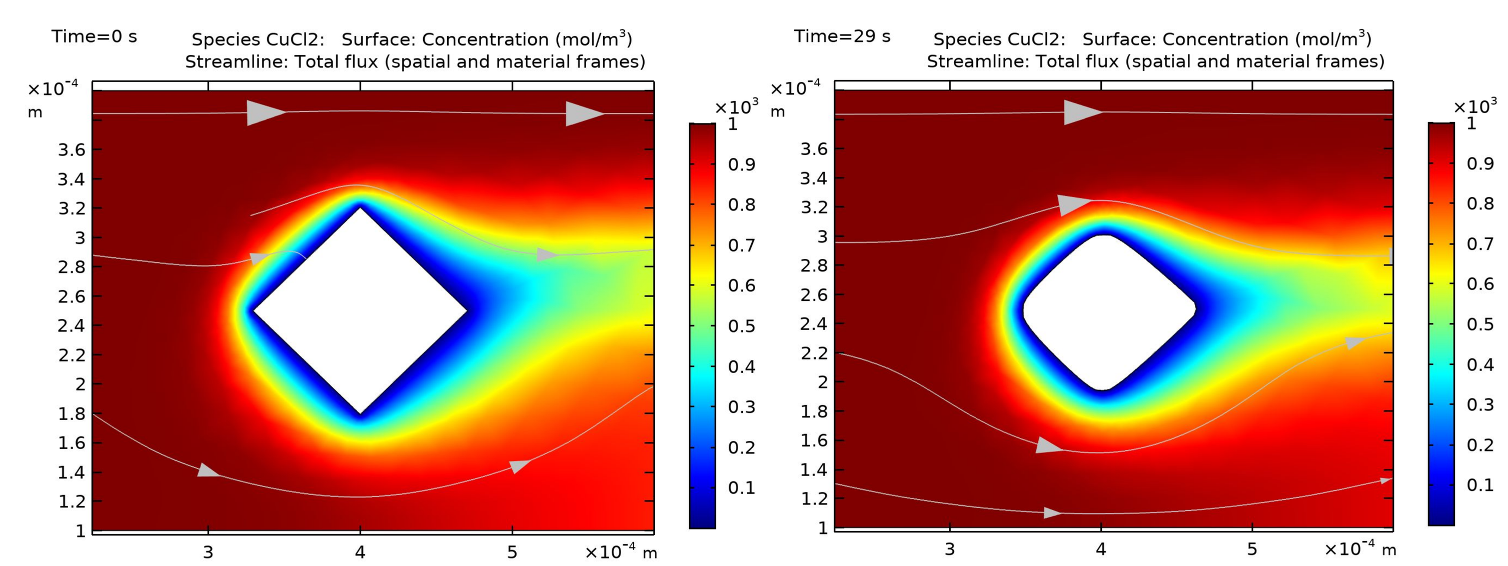
Model Testing
- Varying part orientations
- Varying etchant concentrations
- Implement agitation

Quantitative Validation
- Test model parameters with experimental data

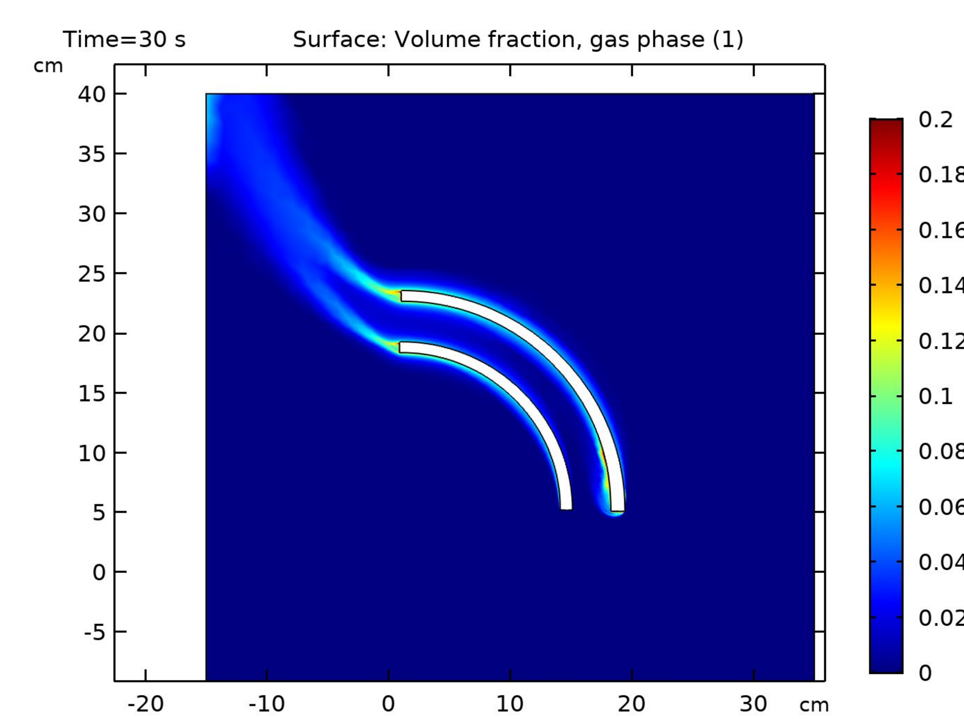
Predictive Model
- Output model that encompasses all physics

RESULTS

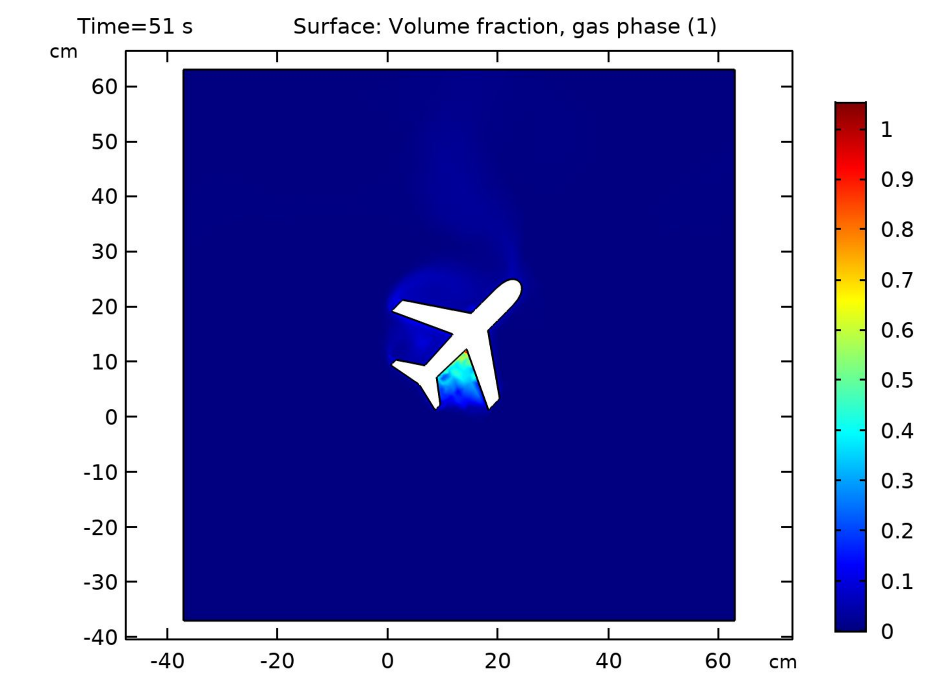
- Model simulates an accurate milling rate based on the 0.001 in/min per side industry estimate
- Model simulates stoichiometrically accurate gas generation, mesh change and etchant consumption
- Temperature, fluid flow, gas volume fraction, acid concentration and mesh change are modeled within qualitative reason
- Model functions with novel geometries, parts with entrapment regions and internal surfaces, varying orientations, as well as with forced convection implemented



COMSOL simulation showing the part boundary at the beginning (left) and end (right) of the simulated milling process



COMSOL simulation showing a part with internal geometry



COMSOL simulation depicting gas entrapment in a concave part geometry

CONCLUSION

A more advanced chemical milling model was developed that takes into account gas generation, part milling, and heat generation. However, limitations of our assumptions were identified, including limitations with COMSOL itself. Validation with experimental data is necessary to verify that our model can accurately predict the results of chemical milling on a titanium part

Future work would include:
- **Simulation validation:** Validate model using data from The Boeing Company
- **Optimization:** Modifying parameters and possibly utilizing supercomputing to shorten run times
- **Pursuing non-FEA Models:** Pursue a boundary element method (BEM) model to provide better gas/liquid boundary simulation.

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