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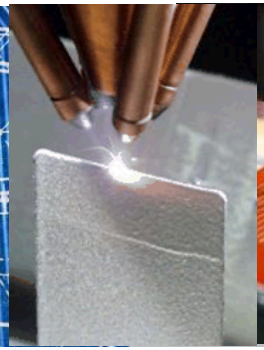

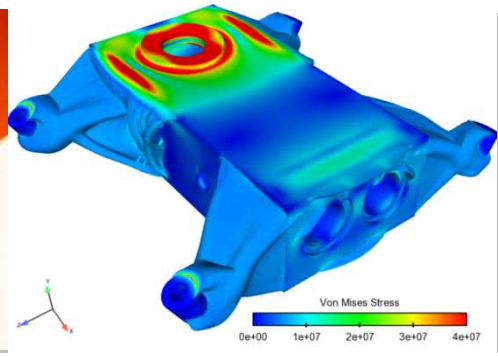

Residual Stress Reduction in LENS 3D Printed Metal Parts

Shaun Whetten, David Keicher

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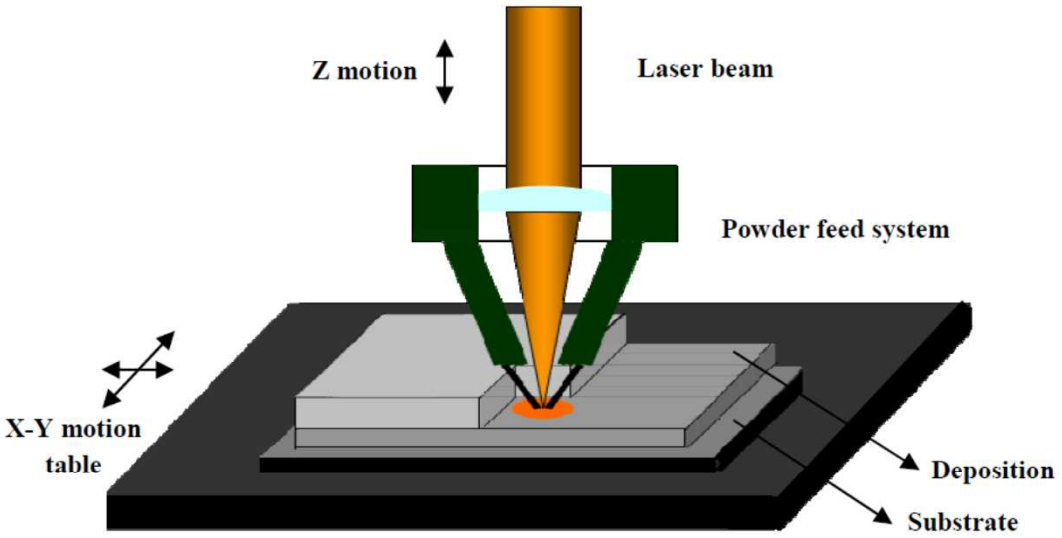
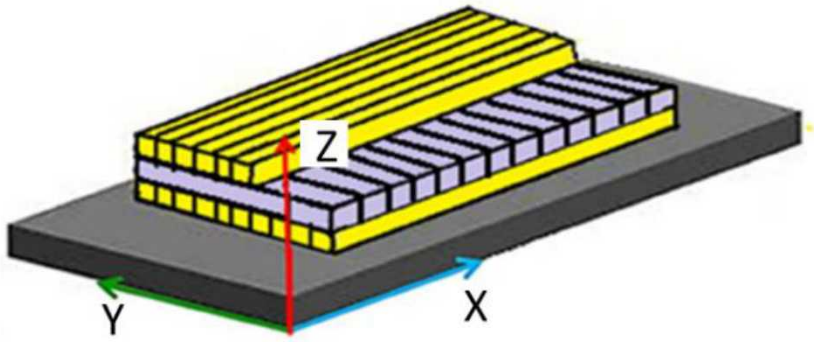
LENS

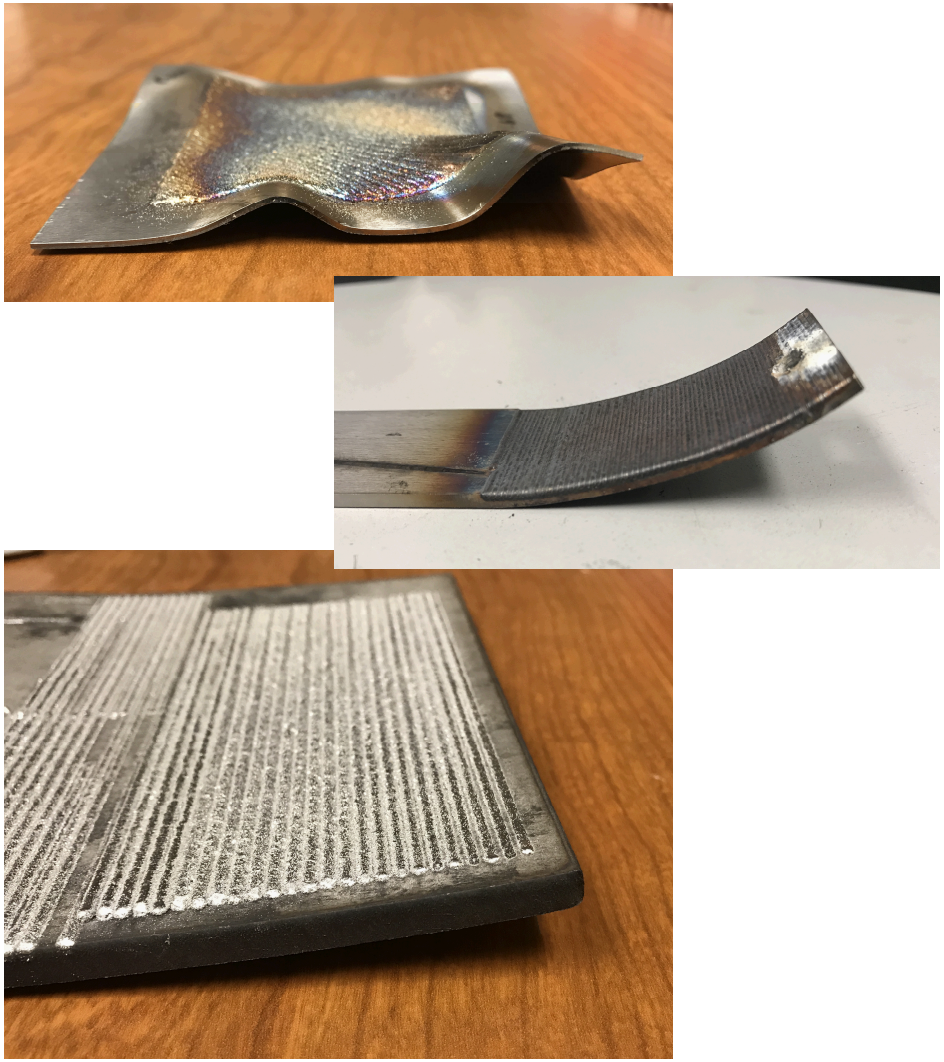
- Laser parallel to z axis creates melt pool
- Powdered metal feed into melt pool creates deposition
- X-Y motion table moves substrate to create continuous weld bead
- Z motion controls layer height





What is the problem

- Rapid heating and cooling during print causes residual stress buildup
- Stress buildup causes distortion, warping, and even cracking of printed part.
- Problematic when higher tolerances or repair jobs are desired
- Stress often manifests itself in substrate deformation



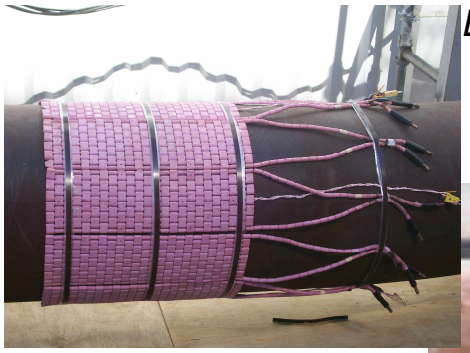
The welding solution

Why do welders preheat?

- Can raise some metals above brittle fracture temperature
- Reduces shrinking stresses between weld and base material
- Reduces cracking

Our approach

- Use electrically heated platen to preheat substrate
- Measure deformation of substrate at various heat levels



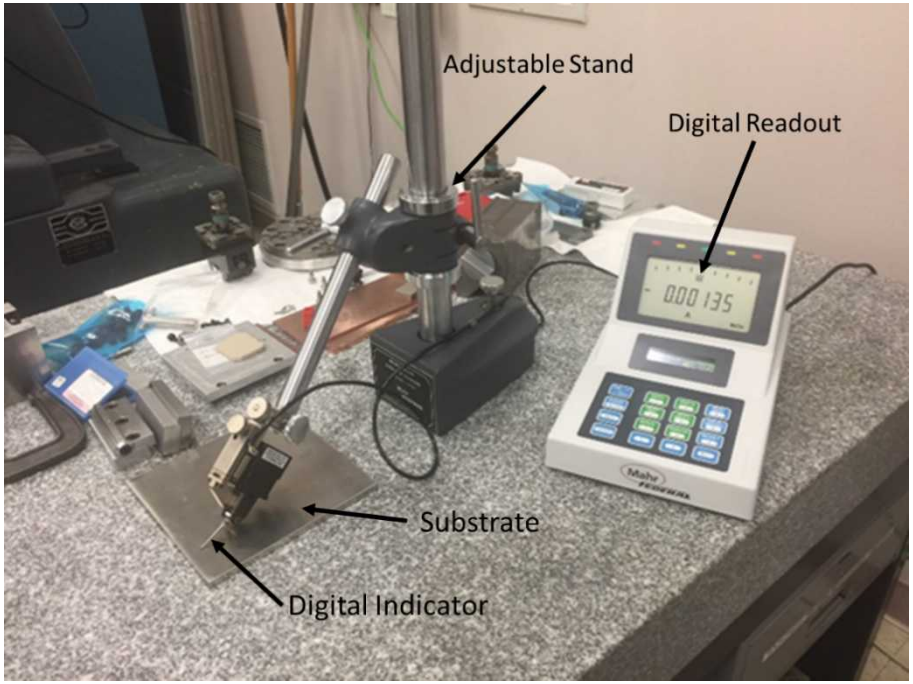
Electrical heating

Induction heating

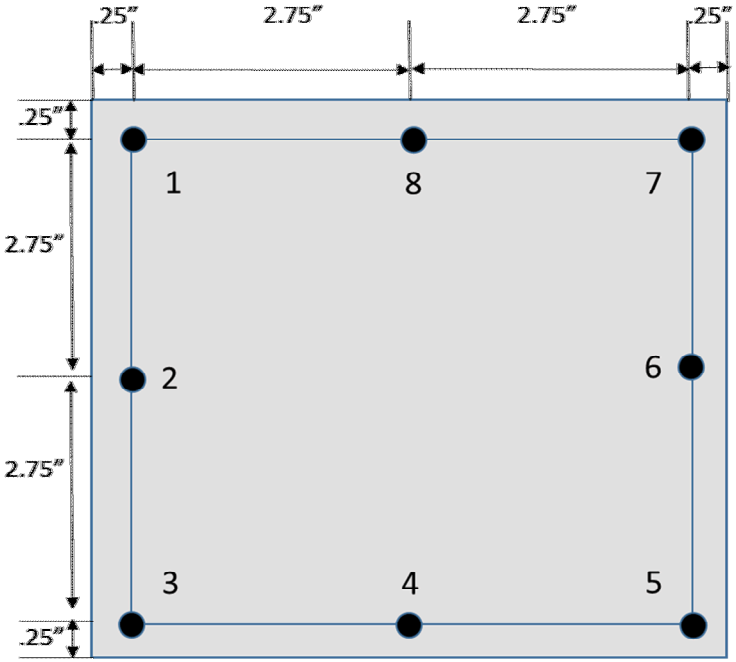
Torch heating

Measuring flatness before print

- 6”x6”x.25” precision ground 304L substrate
- Measurements taken in 8 locations



Substrate measurement setup

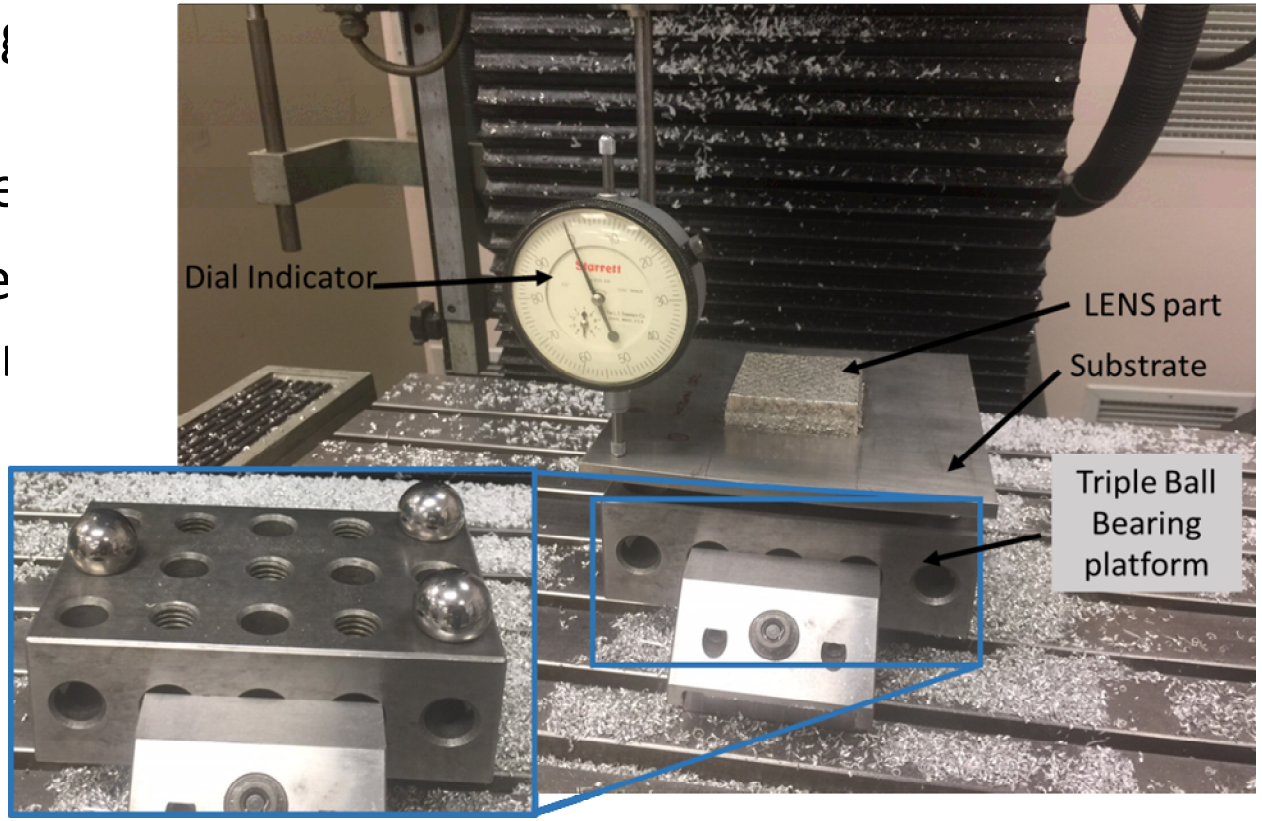


8 substrate measurement locations

- Measured on granite slab for accuracy
- Measurements taken with digital indicator

Measuring flatness after print

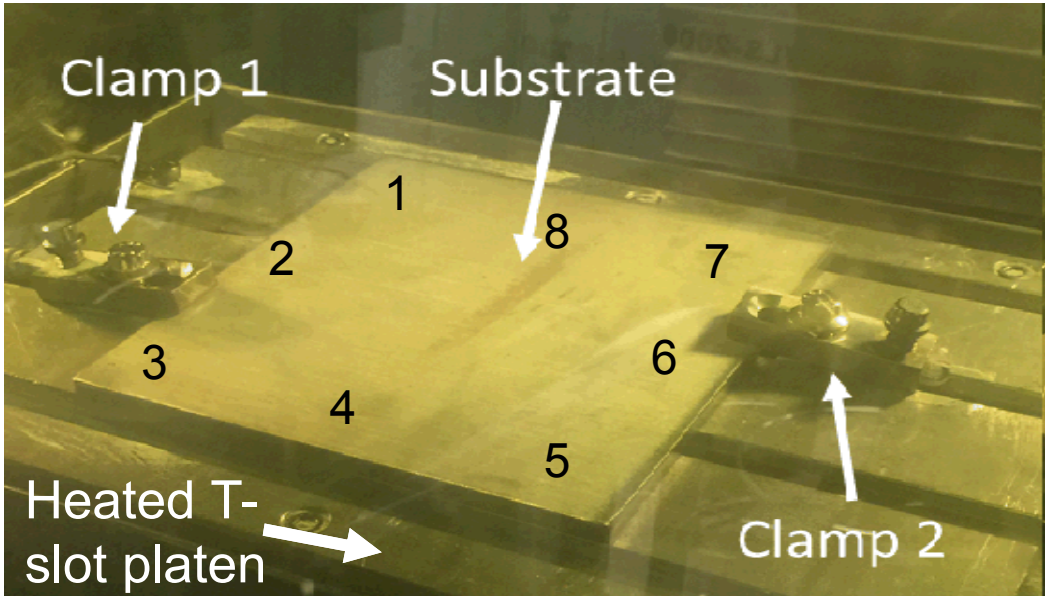
- Triple ball bearing platform used to warped substrate
- Dial indicator use take measureme
- Measurements taken in same 8 locations as before print



Substrate measurement setup

Initial preheat study

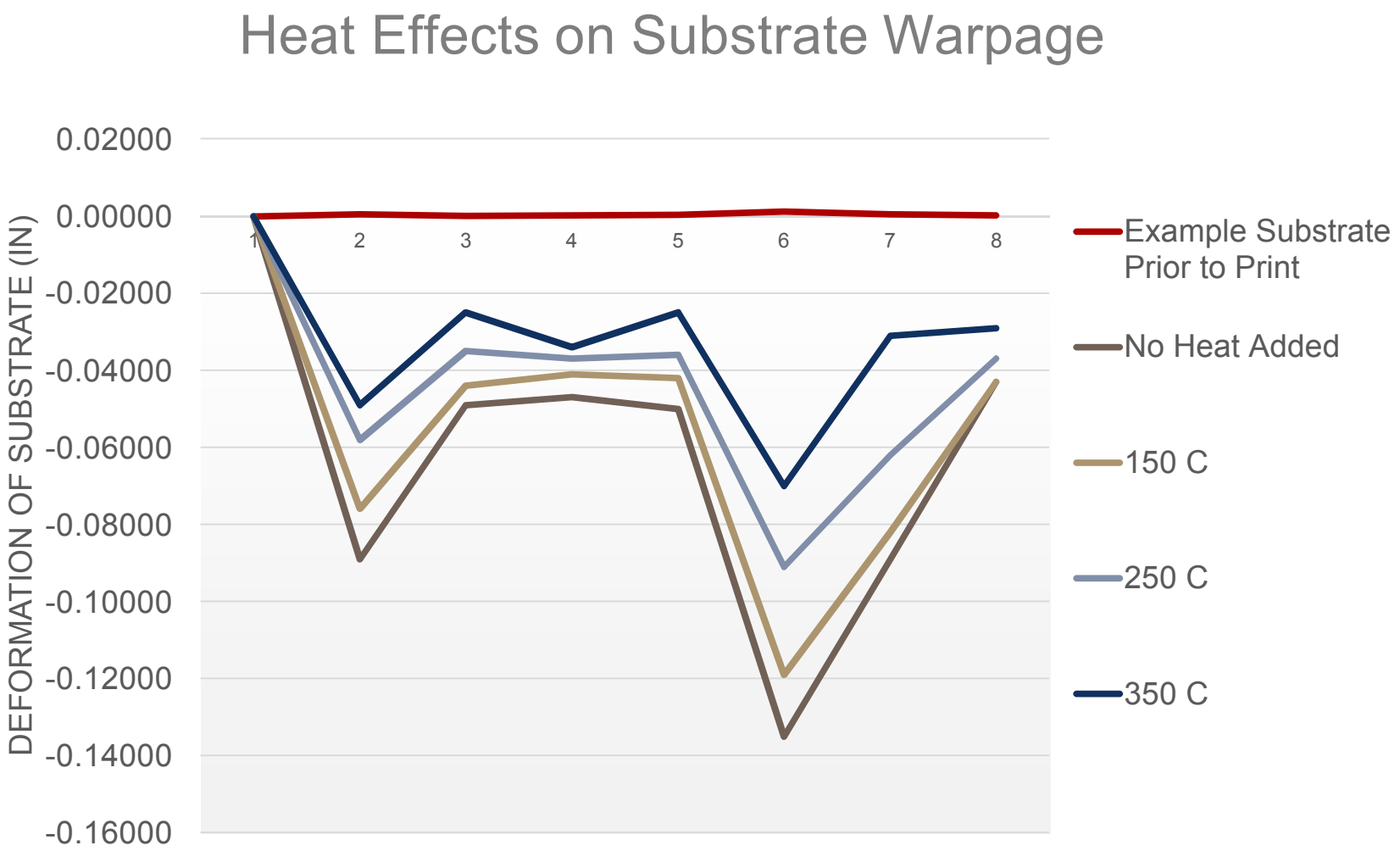
- 2 substrate clamps on opposite sides of the substrate
- Samples printed with platen at temperatures of 35°C, 150°C, 250°C, and 350°C
- Printed a 2.1”x2.1”x0.6” blocks



Process Parameters

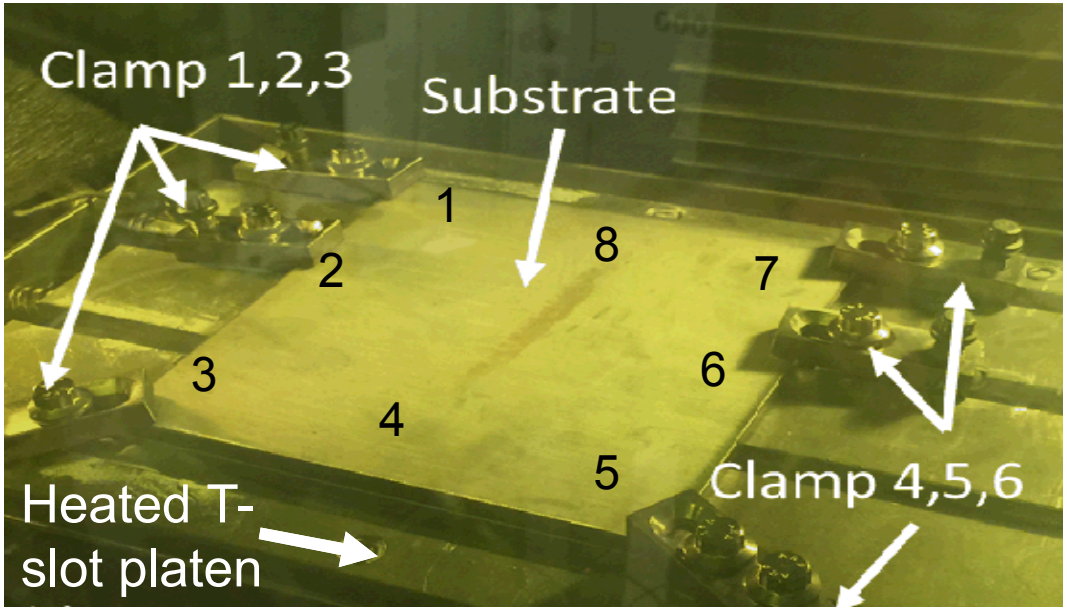
Laser Power	500 [W]
Powder Feed rate	2.1 [g/min]
Layer Thickness	0.25 [mm]
Hatch Spacing	0.8 [mm]
Parameter Deposition Speed	450 [mm/min]
Infill Deposition Speed	600 [mm/min]

Initial preheat study results



Extra clamping

- 6 substrate clamps- one in each corner, and one in the same locations as before
- One sample printed at 250°C
- Printed a 2.1”x2.1”x0.6” block
- Extra clamps help hold the substrate on the heated platen



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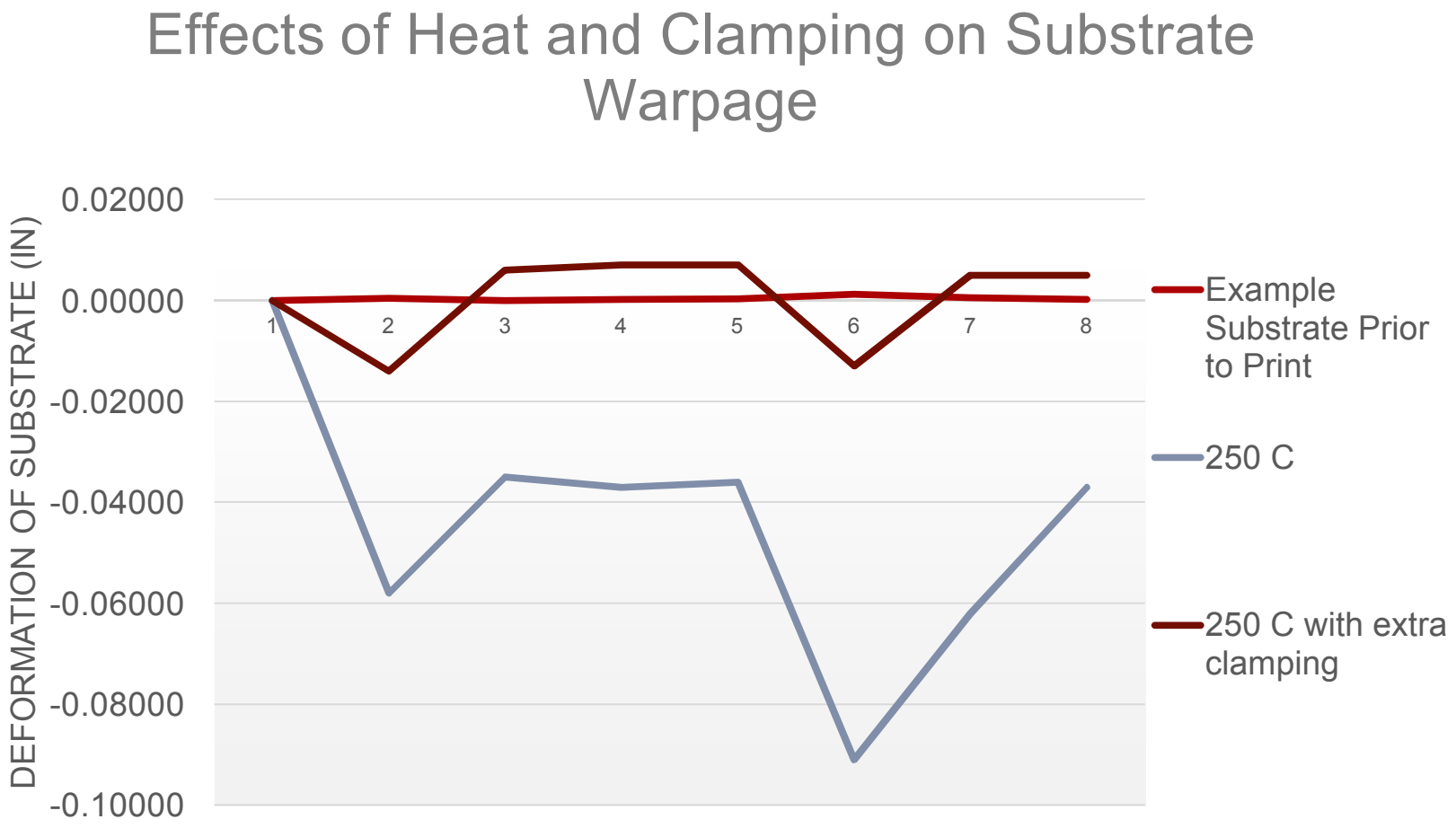
Extra clamping results

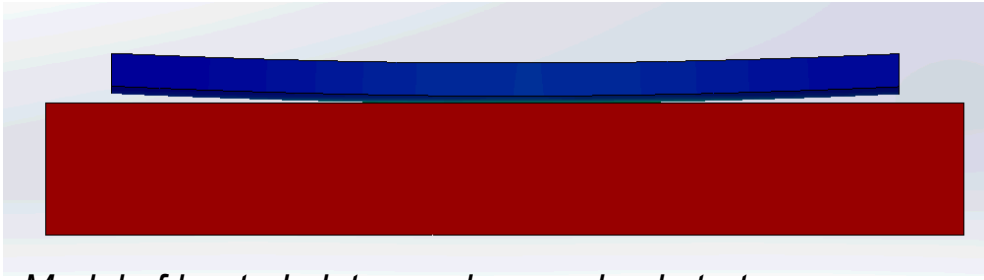


Questions to explore

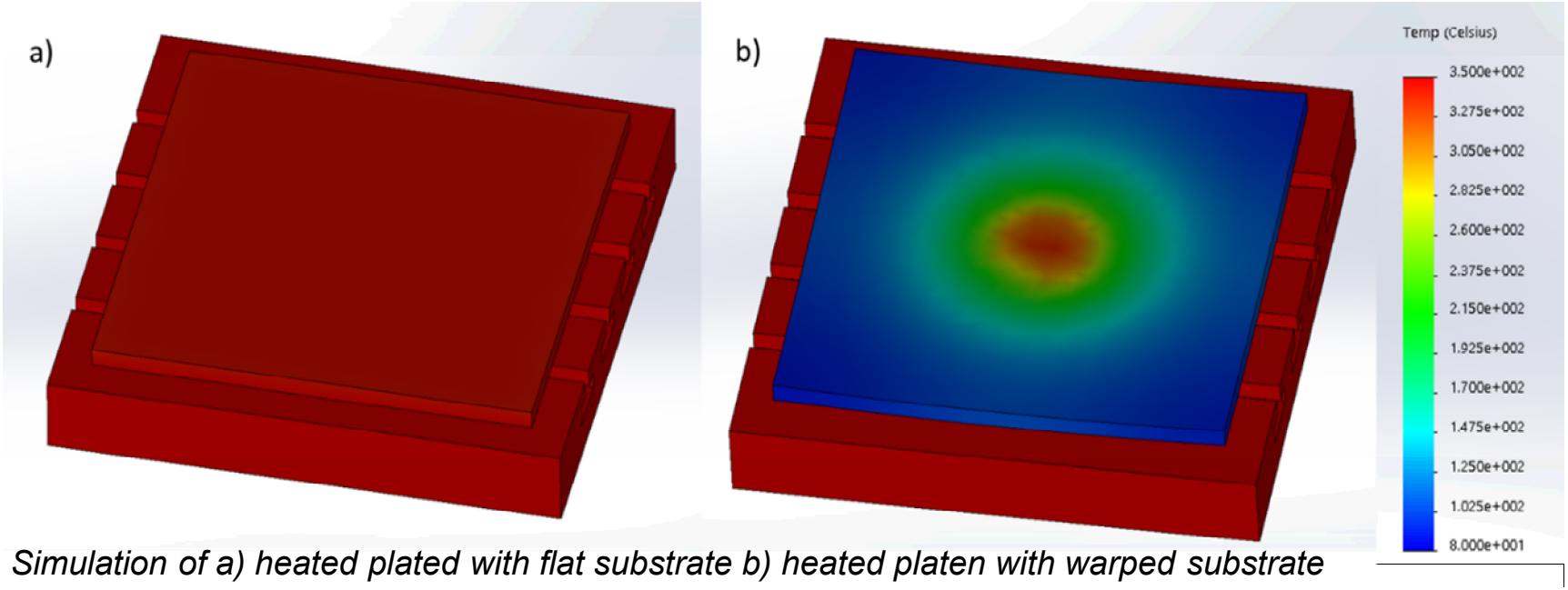
- How does warping affect heat transfer into a substrate?
- How does clamping affect warping and the heat transfer?
- How do substrate heating (bottom) and laser heating (top) affect thermal gradient in printed parts? Are sections of the part at a lower temperature than the temperature of the substrate?
- Is there a lag in substrate heating compared to the platen temperature?
- What substrate temperature is need to minimize stress in 3D printed parts?
- How does part geometry affect the temperature history of a printed part?

Substrate warping

- Simulation shows that controlling distortion enhances heat transfer into the substrate

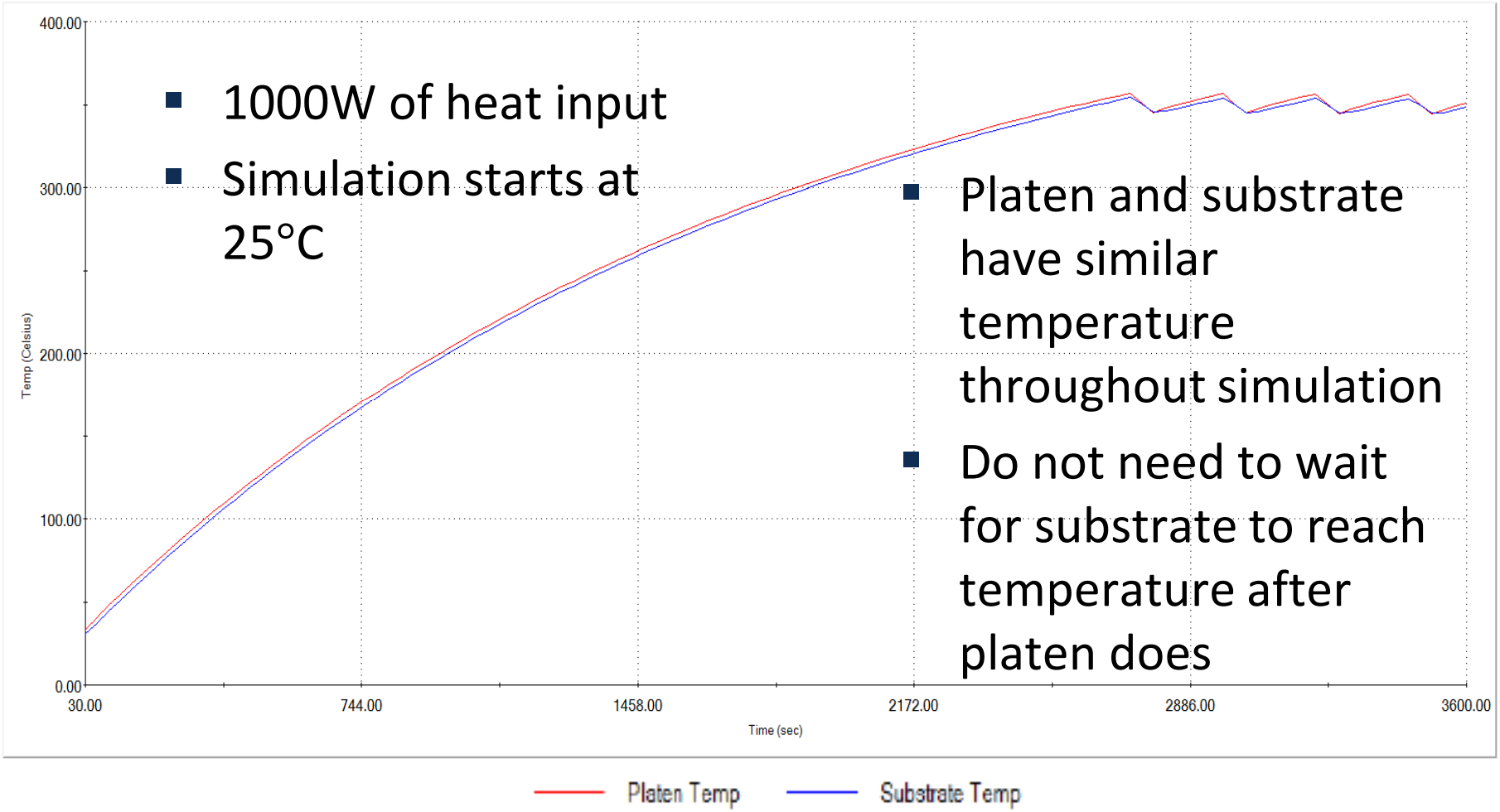


Model of heated platen and warped substrate



Simulation of a) heated plated with flat substrate b) heated platen with warped substrate

Platen temperature vs. Substrate temperature

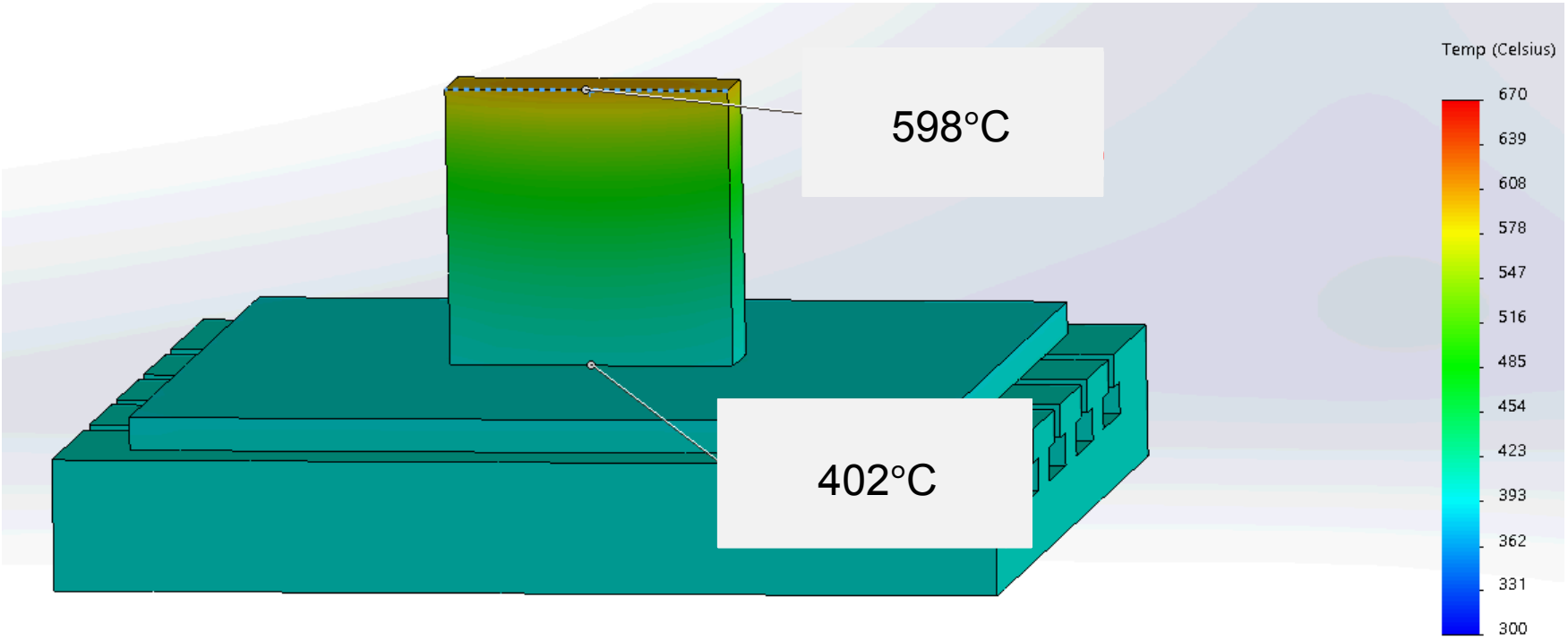


- 1000W of heat input
- Simulation starts at 25°C

- Platen and substrate have similar temperature throughout simulation
- Do not need to wait for substrate to reach temperature after platen does

3D printed part temperature gradient

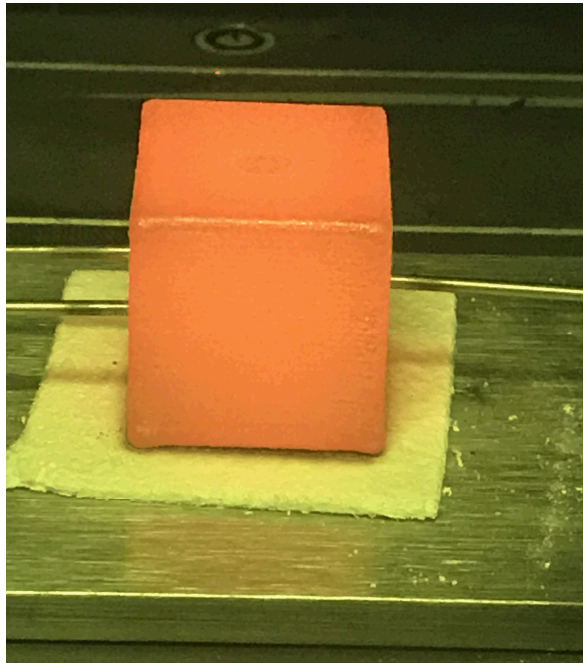
- Represents heat input from platen and the laser
- Total volume of the part is at 400°C or higher



Stress relieving temperature – 304L SS

Referencing the British Stainless Steel Association

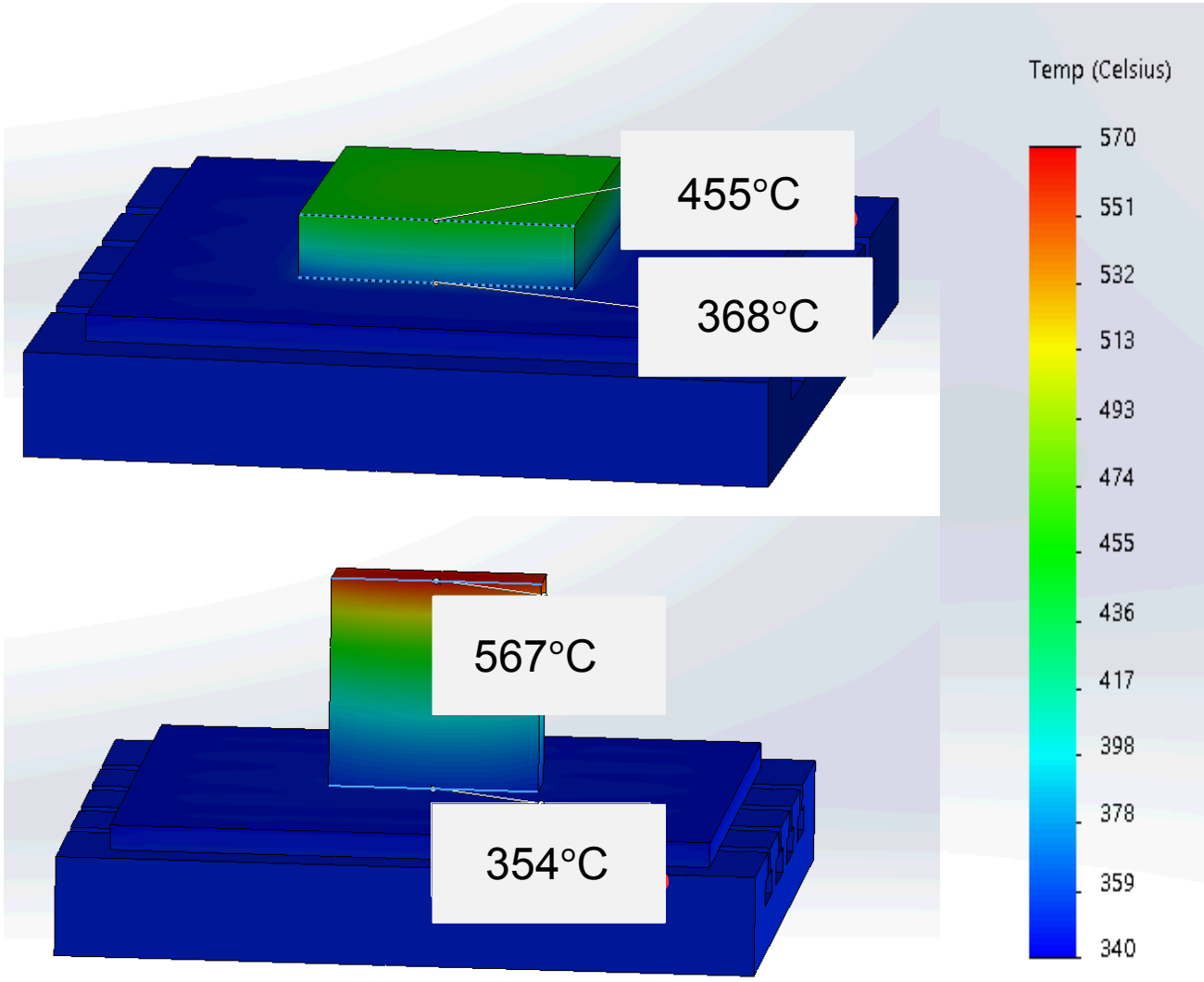
- Dimensional stability heat treatment
  - Heat to 475°C
  - Slow Cool (approx. 4hrs per 25mm of section)
- In general (to avoid sensitizing the stainless steel) stay away from 480°C - 900°C range
- The low carbon 304L or 316L should not be at risk of corrosion sensitizing



How hot to relieve stress?

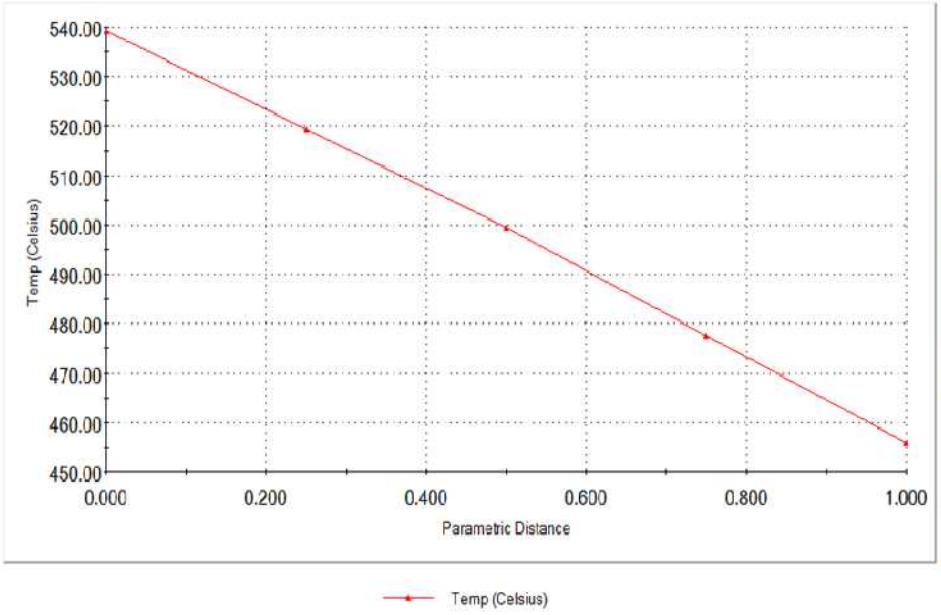
Part orientation

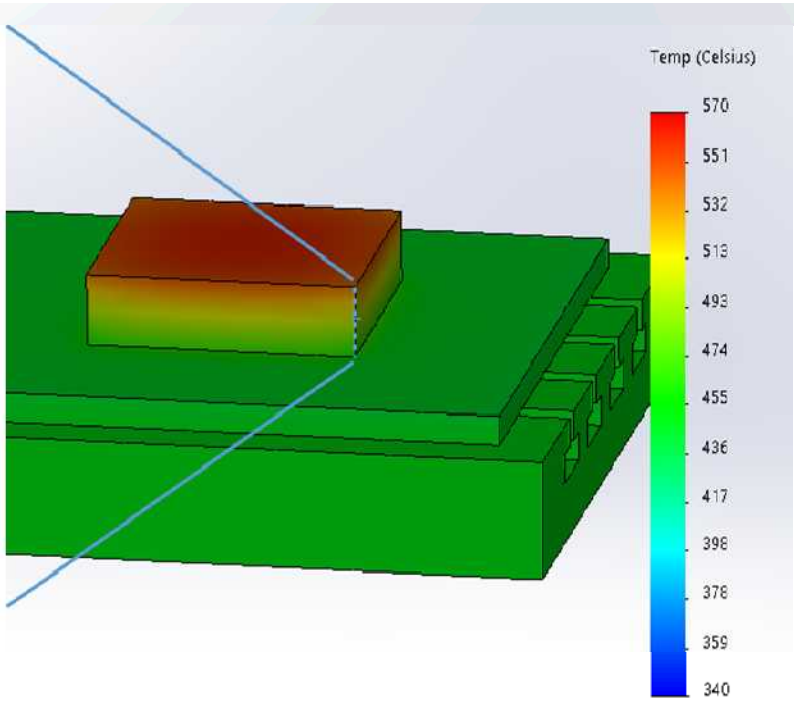
- Orientation of the 3d printed part changes the thermal gradient
- Tall, thin parts have a higher temperature at the build plane



Platen temperature - horizontal

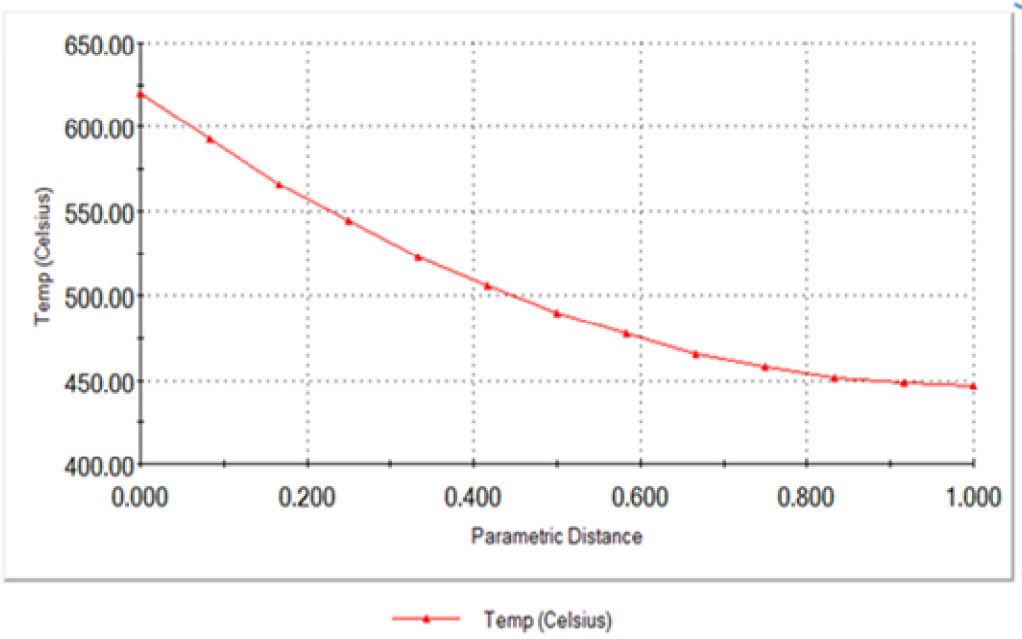
- Platen/ substrate temp of 450°C
- Almost 80% of the 3D printed part is at 475°C or higher
- For a 6 hour build over 4.8 hours worth of the print is exceeding the desired 475°C

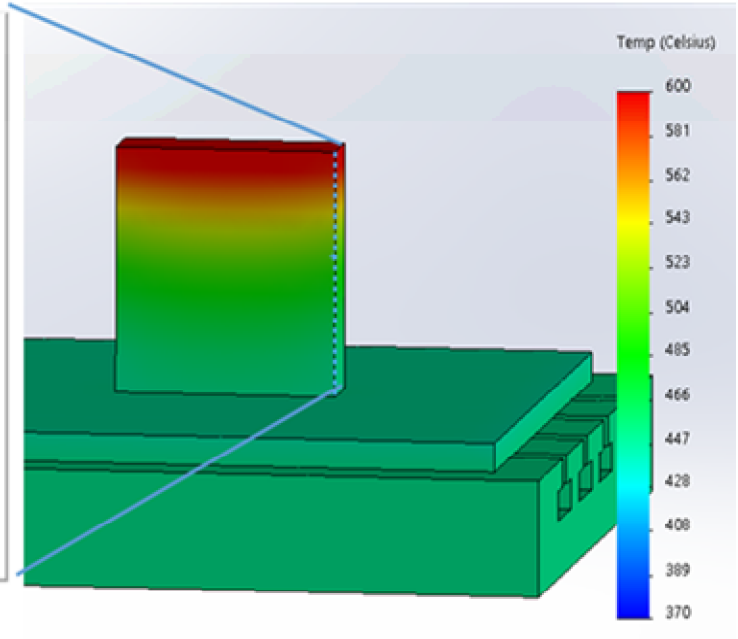




Platen temperature - vertical

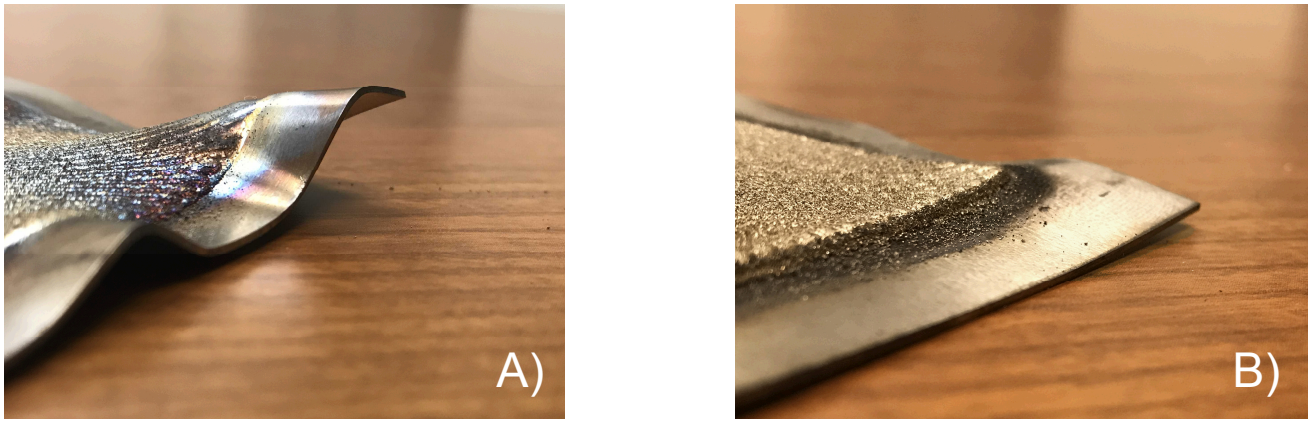
- Platen/ substrate temp of 450°C
- About 67% of the 3D printed part as at 475°C or higher
- For a 6 hour build 4 hours worth of the printed part is exceeding the desired 475°C





Conclusions

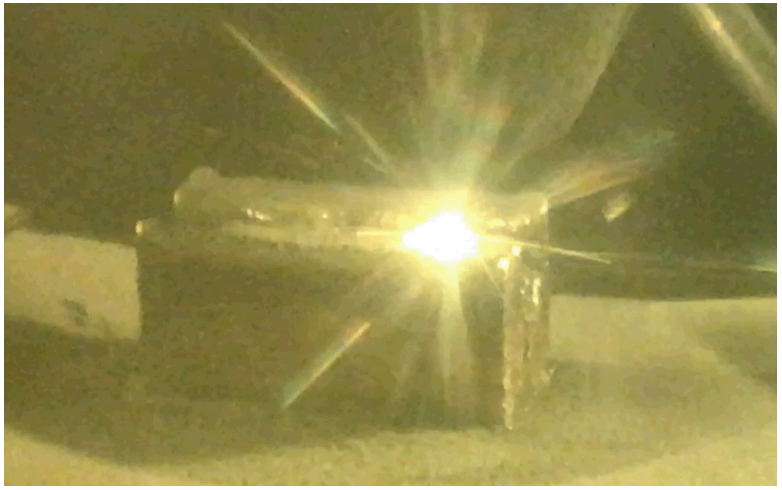
- Part orientation- Different thermal gradient leads to different microstructure
- Effectively clamping your substrate- need to maintain contact with platen for stress to be relieved
- Heated platen- a temperature of 450°C – 475°C is required for stress relief



Printing of 3 layer pad on 0.030" shim stock A)No added platen heat. B) Platen temperature of 450°C.

Impact and future work

- Impact
  - Less warping in parts
  - Improves ability to repair parts
  - Print on thinner substrates
  - Minimizes need for post print heat treatments
  - Greater material selection
- Future work
  - Greater understanding of clamping, preheating, and stress relationship
  - Improve clamping
  - Utilize more sophisticated techniques for measuring stress
  - Expand to other materials



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Resources

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