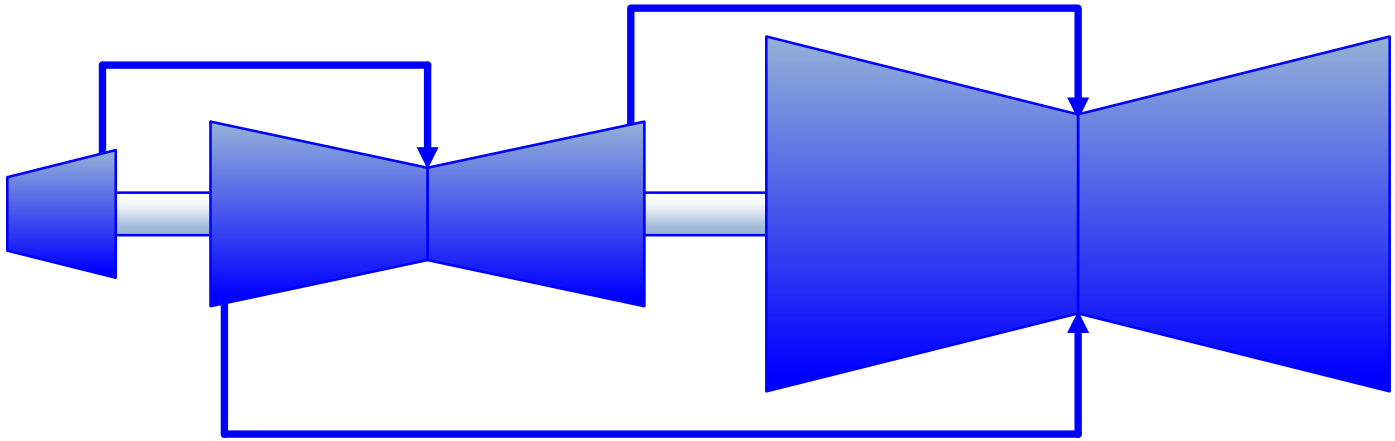
Creep and Tensile Properties of Direct Metal Laser Sintered (DMLS) Inconel 738LC Coupons and Comparison to Cast Properties

Jason Wilkes, Ph.D.

Kevin Hoopes

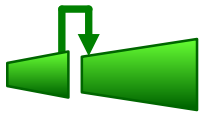
Jon Helfand

sCO2 cycle promises more compact turbomachinery than supercritical steam or helium cycles



5 m

Steam turbine: 55 stages / 250 MW
Mitsubishi Heavy Industries (with casing)



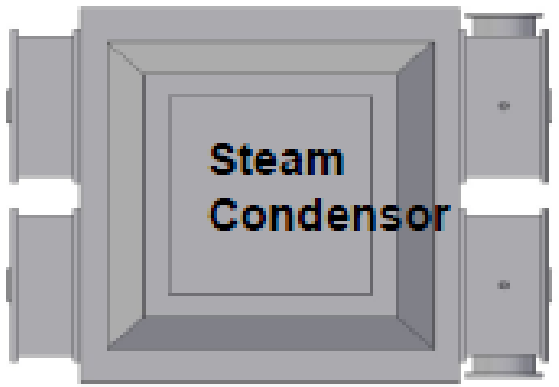
Helium turbine: 17 stages / 333 MW (167 MW_e)
X.L. Yan, L.M. Lidsky (MIT) (without casing)

1 m

sCO_2 turbine: 4 stages / 450 MW (300 MW_e)
(without casing)

Note: Compressors are comparable in size

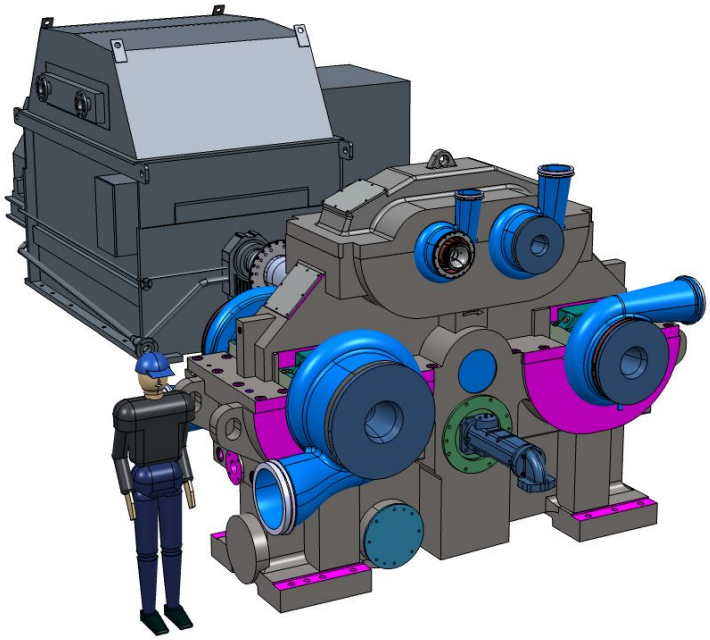
Adapted from Dostal (2004)

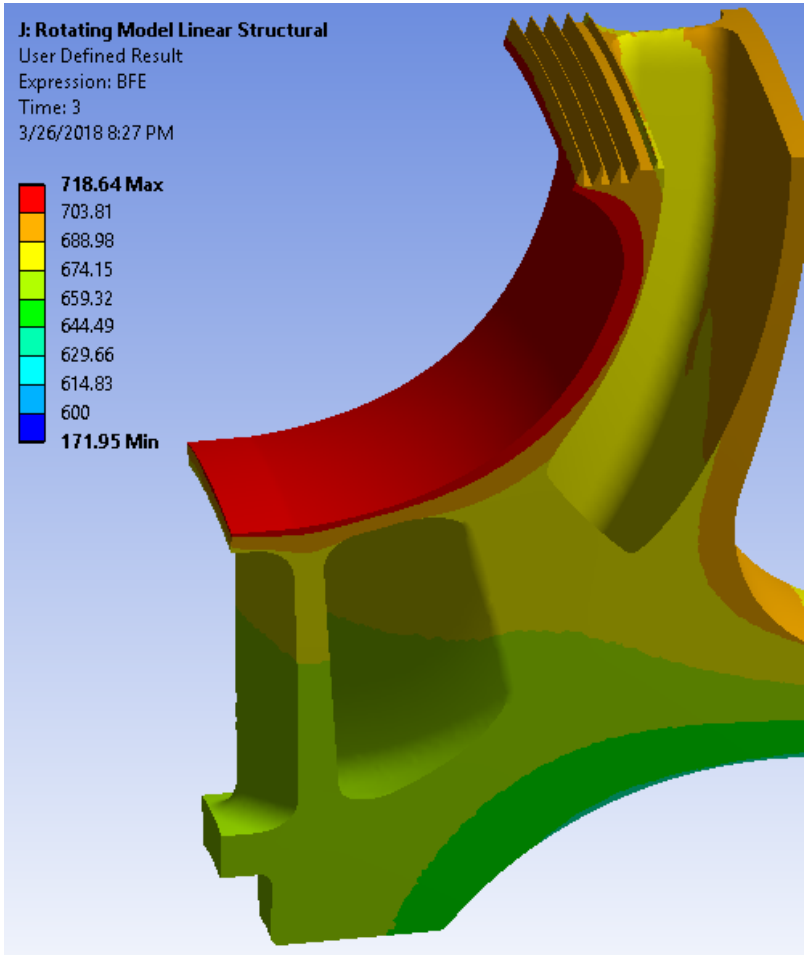


Source: Wright (2011)

A 10MW 275 bar 705°C compact integrally geared radial inflow turbine was designed under DOE-EERE 7114

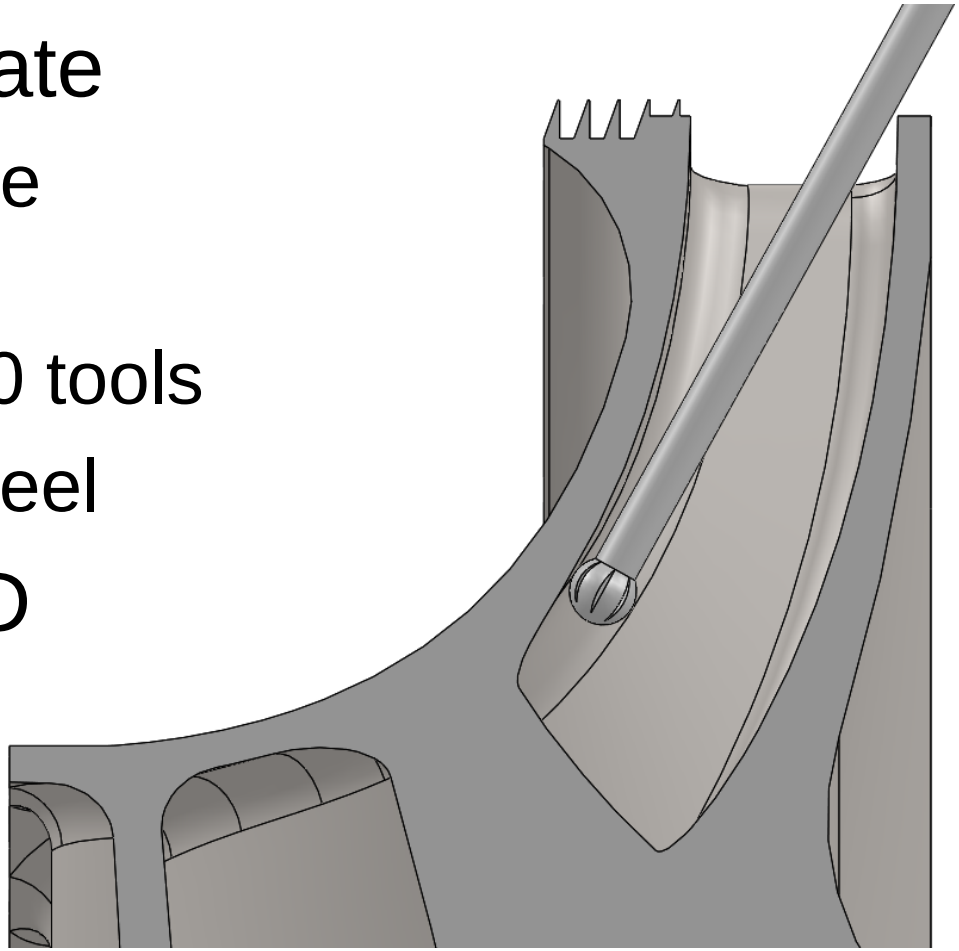
- First Stage
  - Diameter ~ 230 mm
  - Speed ~ 18000 rpm
  - Power ~ 3.5 MW





Whoever said that compact turbomachinery was a good thing never machined a single piece shrouded impeller from Inconel 740

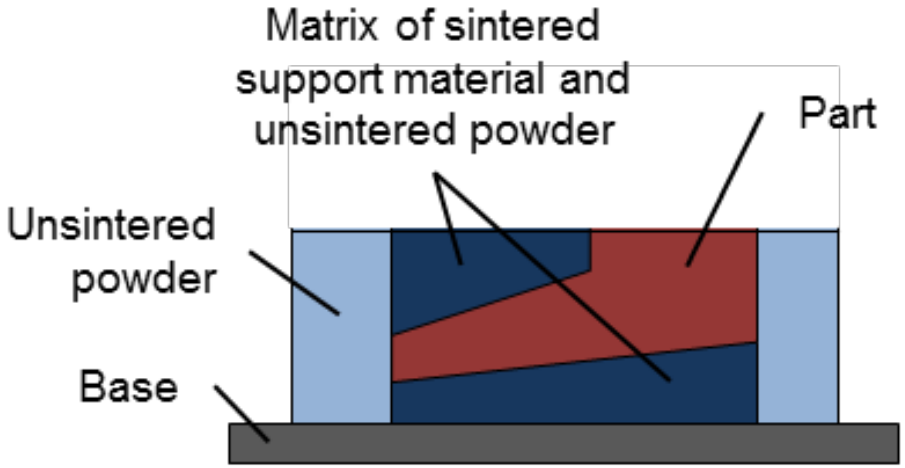
- Quoted Estimate
  - 500 hrs. on the machine
  - $100/tool *500 tools
  - NRE $10k/wheel
- ~100,000 USD



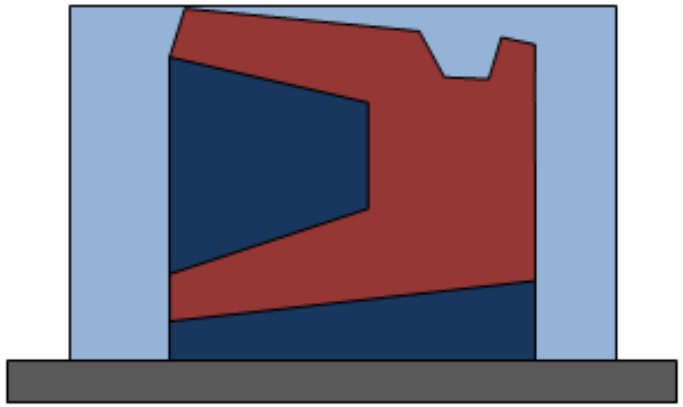
How else can a high temperature closed sCO2 impeller be fabricated?

- 5 axis edm – Very expensive
- Cast Alloy – Received several no-quotes
- DMLS?

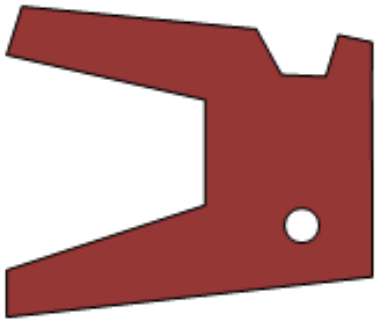
DMLS, SLM, AM Process Overview



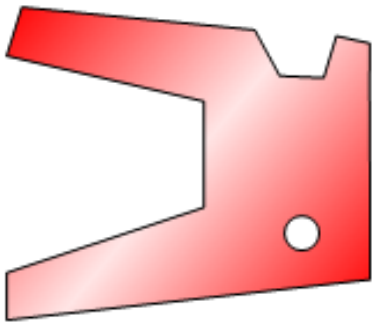
(a) Middle of "growing" process



(b) End of "growing" process



(c) Post-processing: stress-relief, remove supports, rough machining, additional heat-treat



(d) Post-processing: finish machining, surface finish treatment

DMLS in Turbomachinery

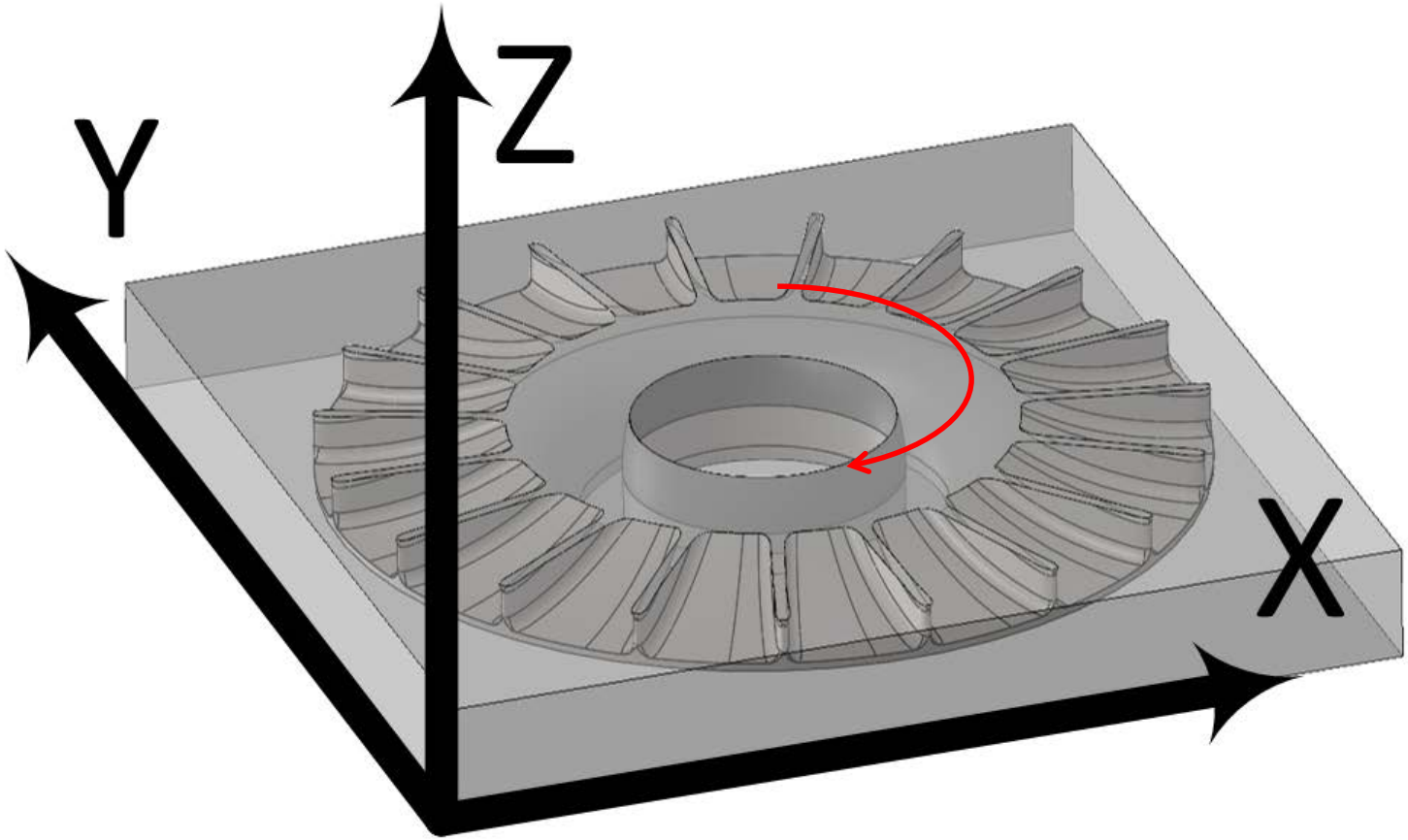
- Published data are scarce
- Stationary and rotating parts have been “printed”
- Published application of DMLS to rotating parts limited to dev
  - 10 wh
  - Ai microturbomachine closed impellers and turbines
    - Overspeed test successful at 1140 ft/s
    - Overspeed test to failure at 1403 ft/s

How does a superalloy manufactured additively compare to cast or forged superalloys?

Helicopter

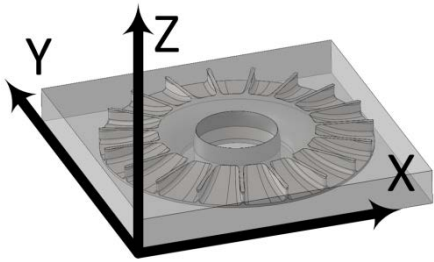
100 krpm GT wheel (Killian 2013)

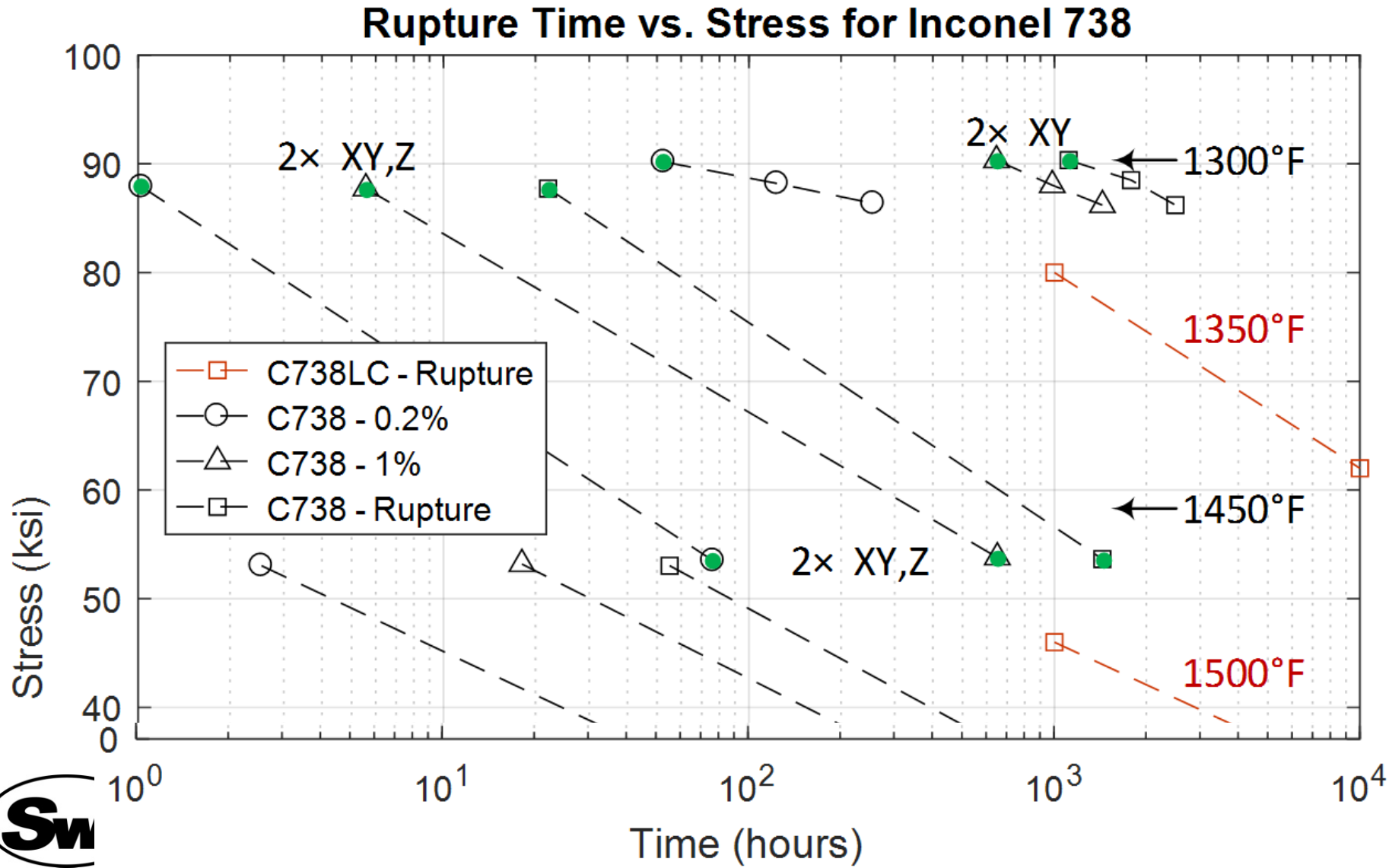
A total of 24 samples were printed



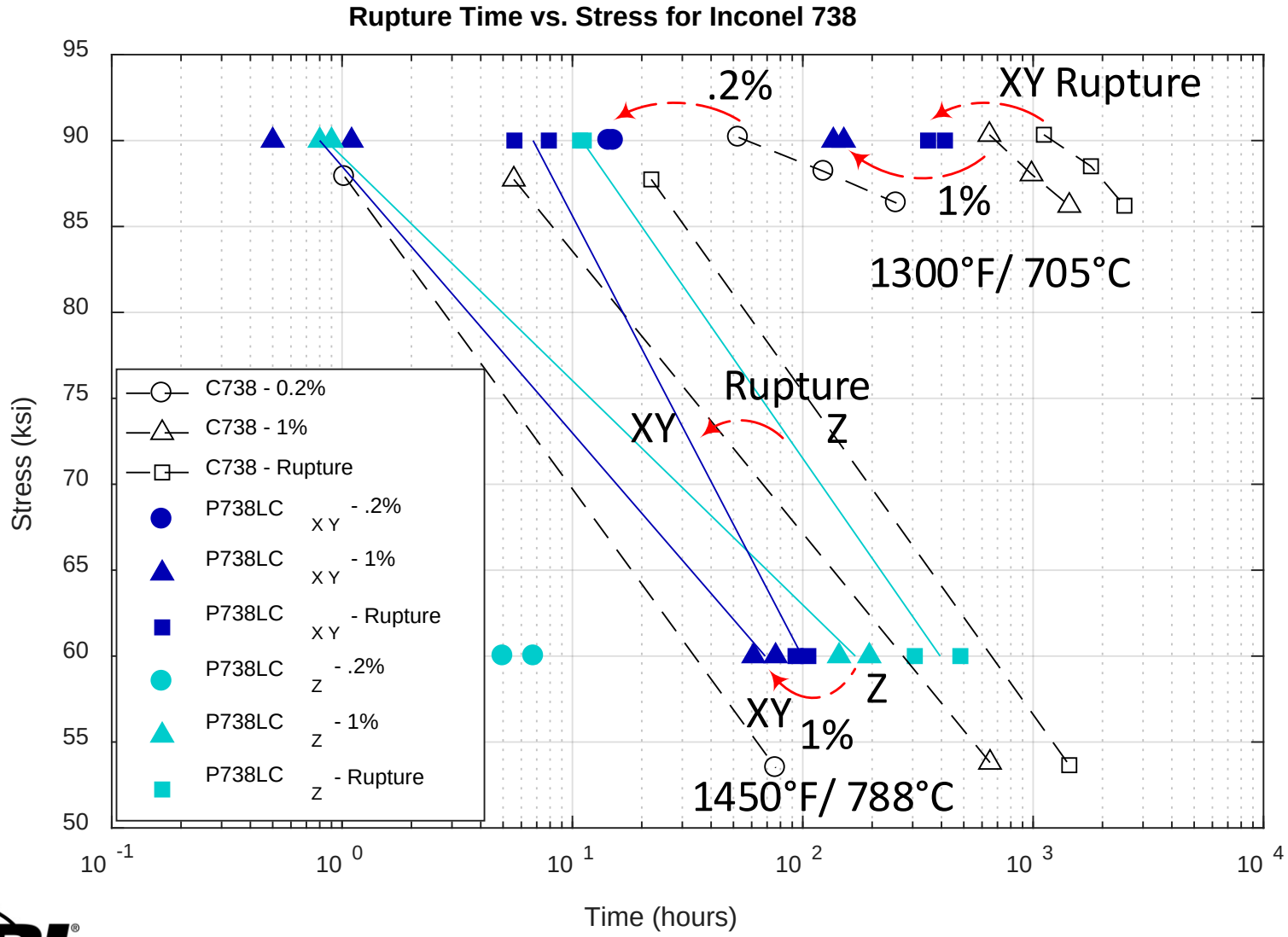
- 14 XY samples
- 10 Z samples

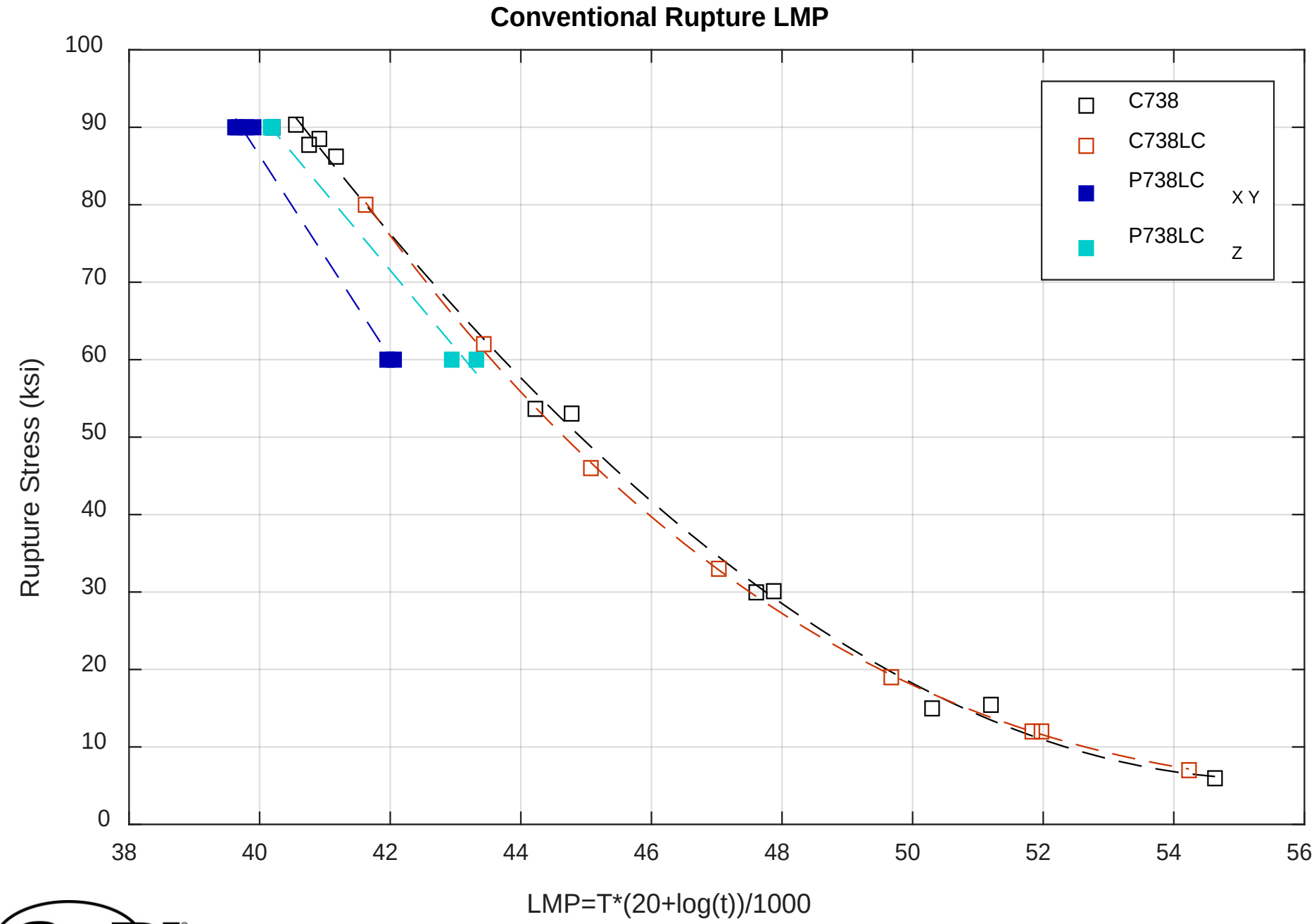
Points were selected to allow for a direct comparison to cast Inconel 738 properties and additionally design stresses at elevated temperatures



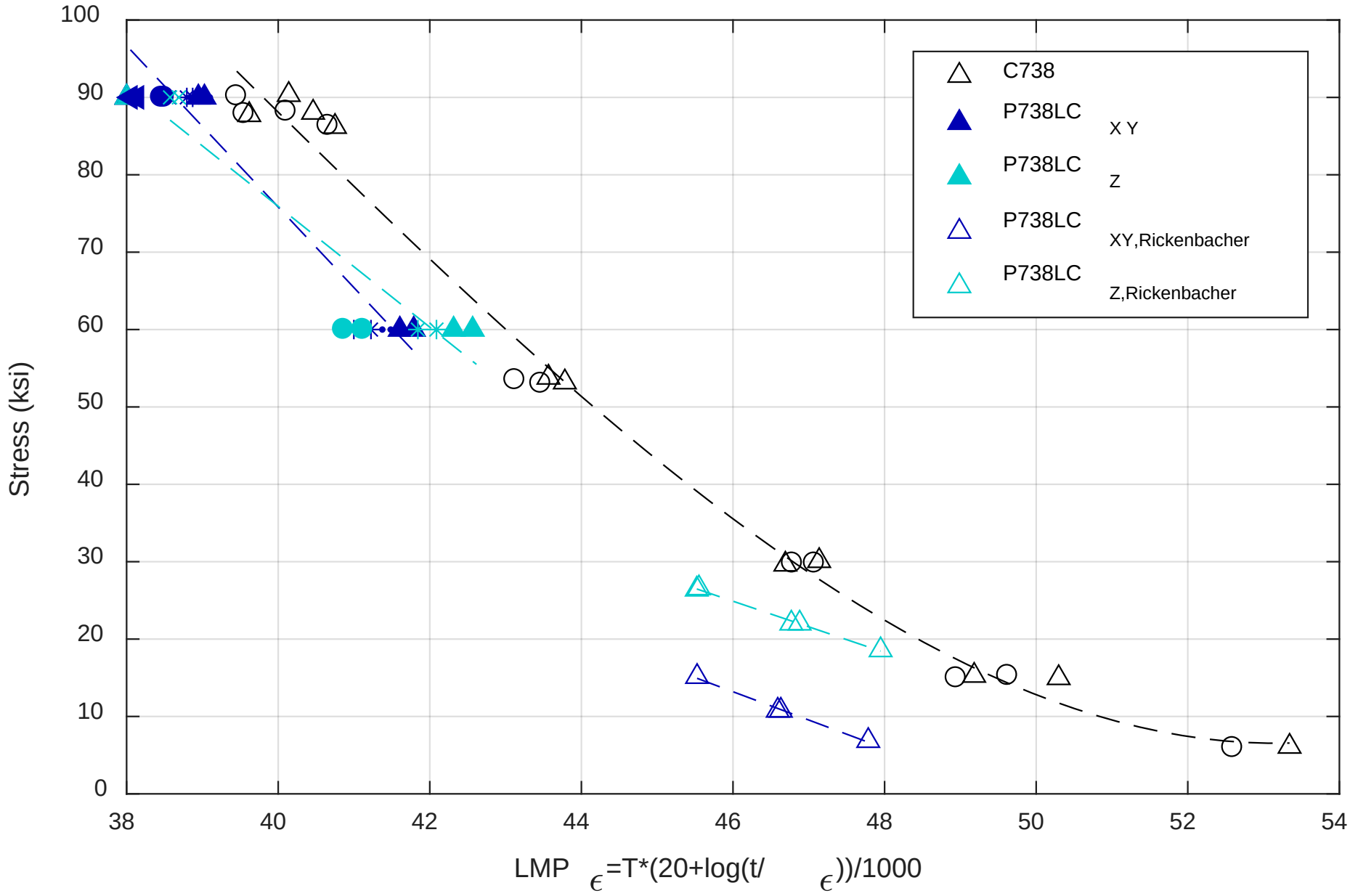


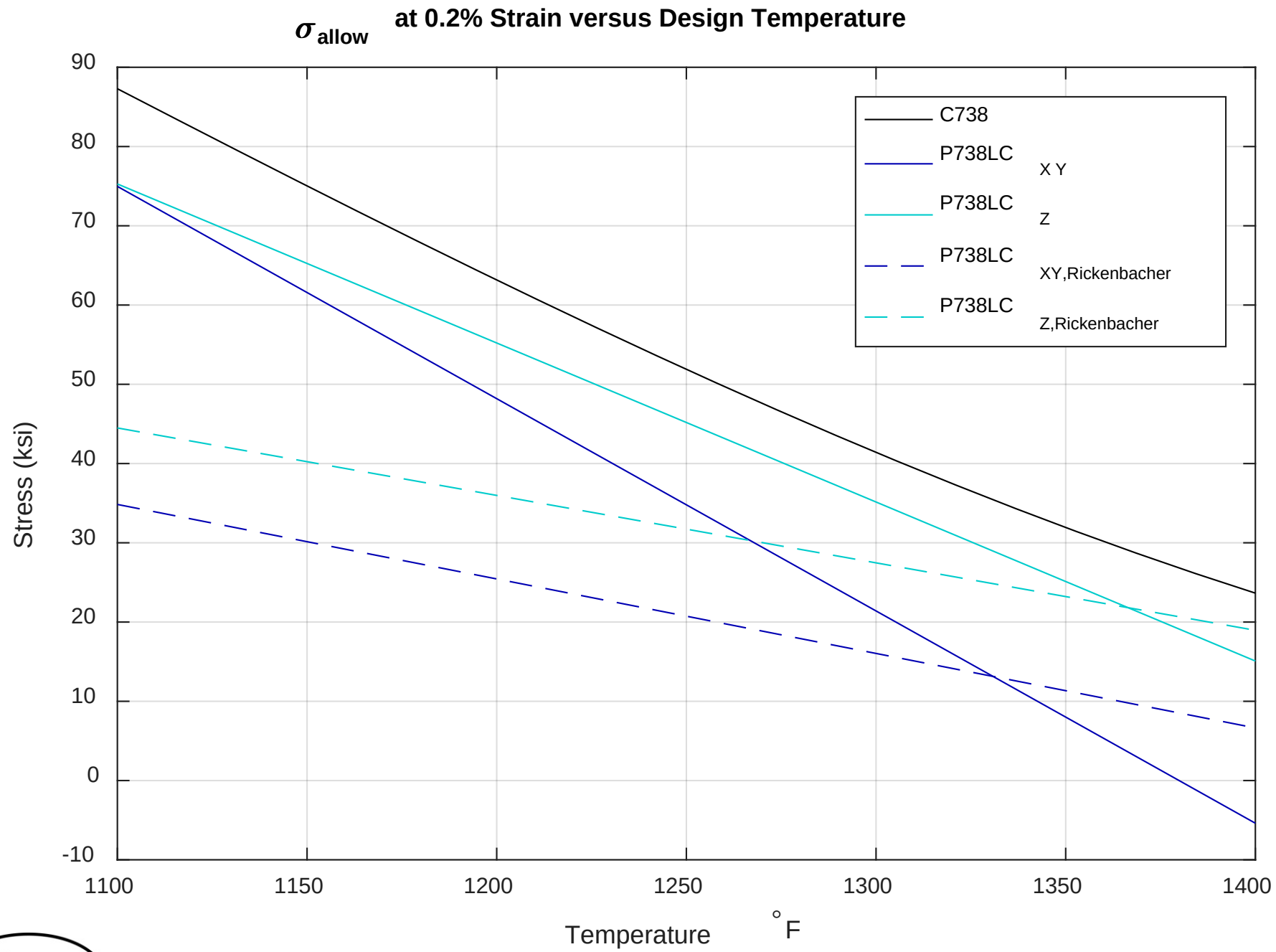
Raw data shows that creeps faster in the XY orientation than in the Z orientation, and that DMLS creep strength is inferior to cast creep strength

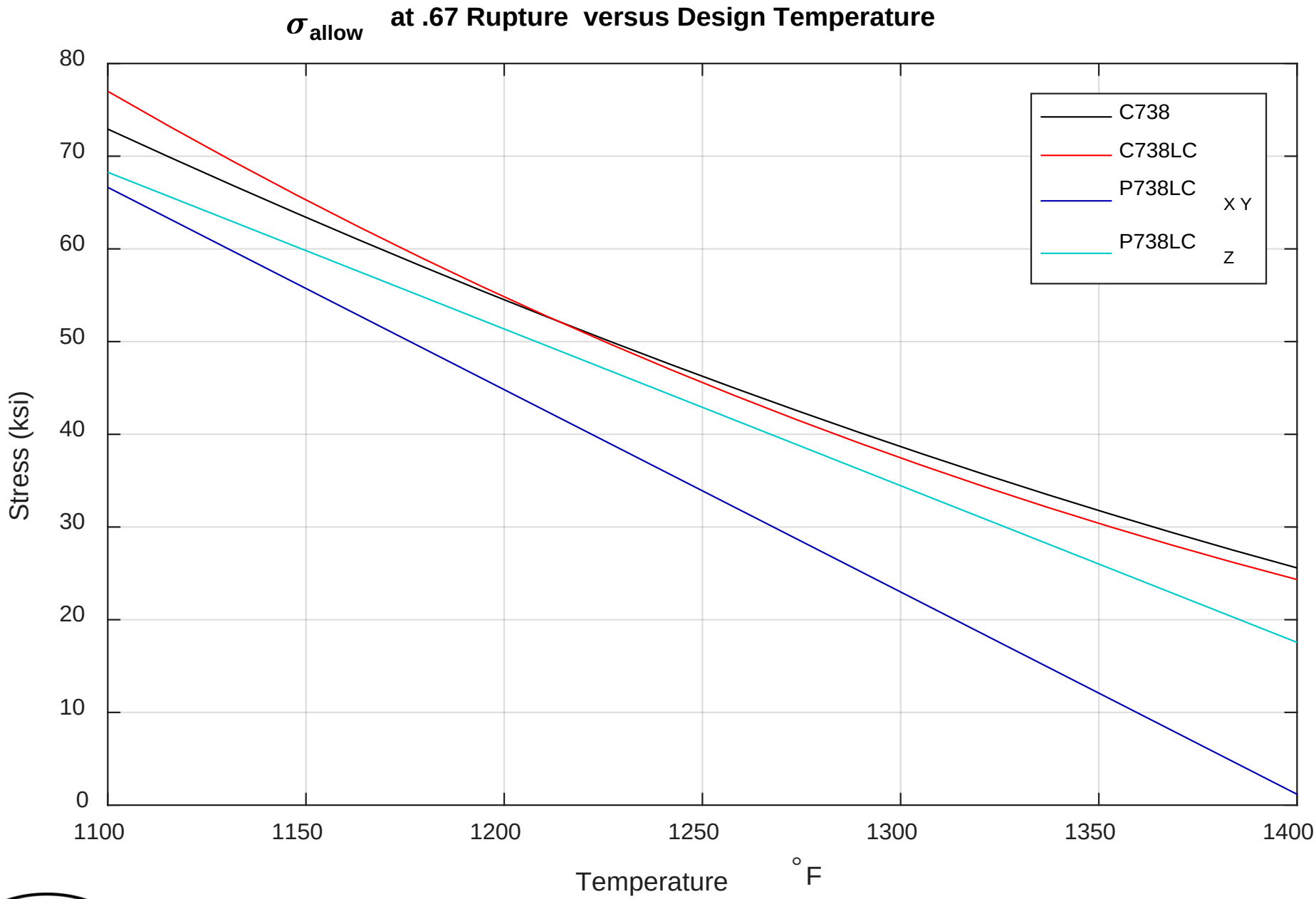




Strain Based LMP

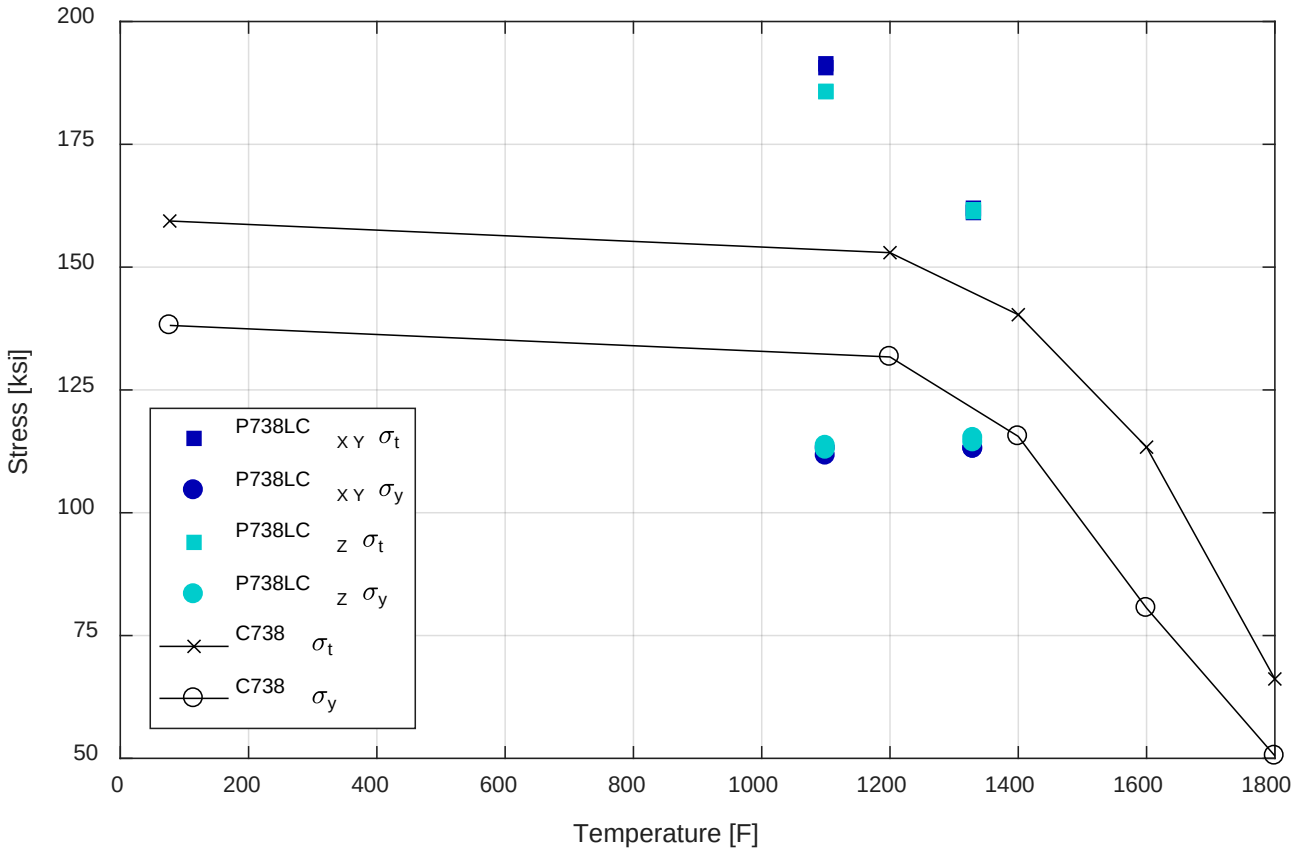




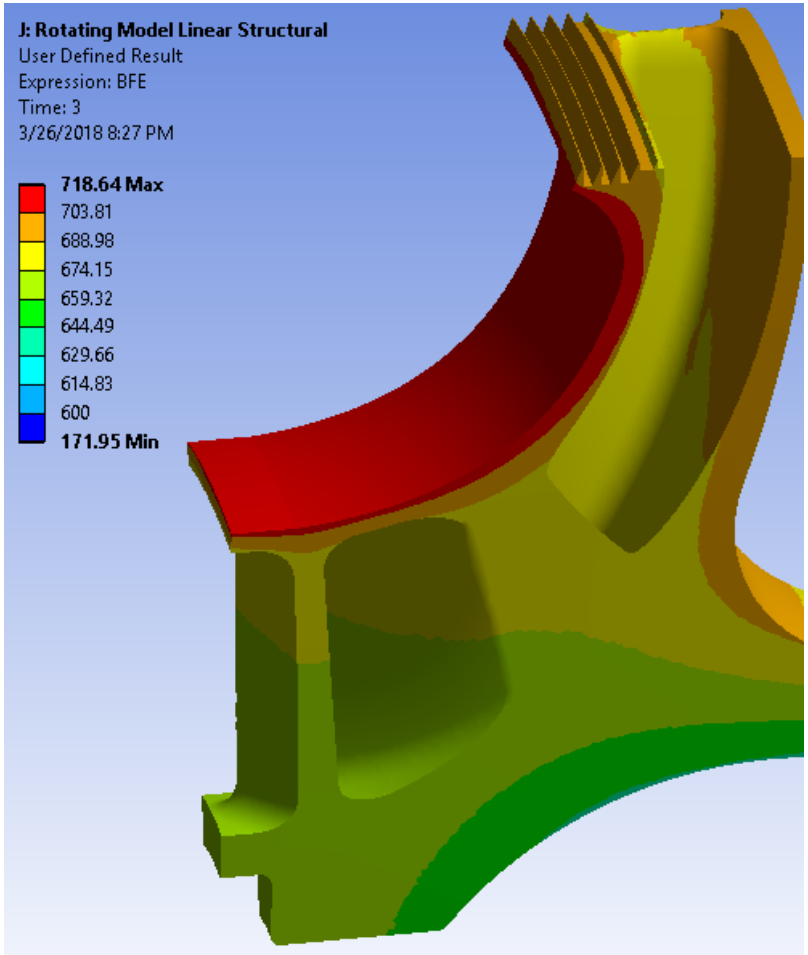


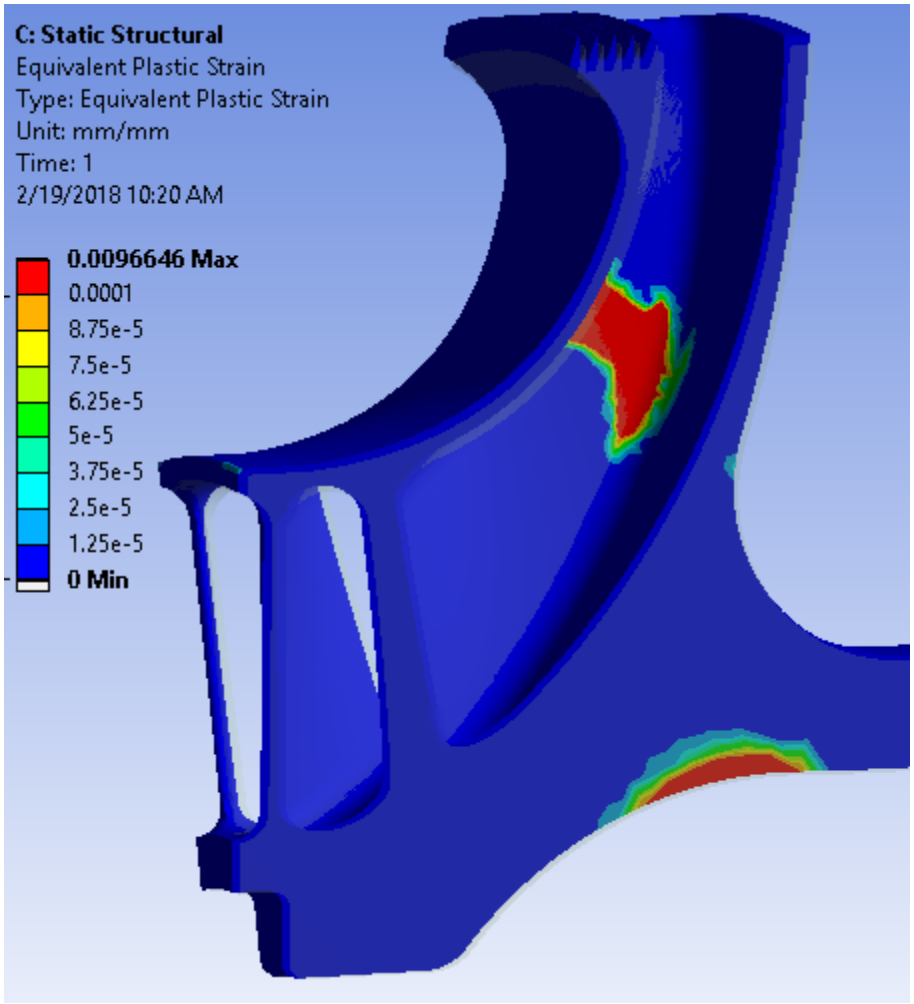
Tensile and Yield properties in the two orientations were generally similar

- 600C
  - 20% ↓ yield
  - 20% ↑ UTS
- 700C
  - 5% ↓ yield
  - 10% ↓ UTS



Per plastic collapse analysis, the impeller should survive 100,000 hrs. without failing due to creep.





Conclusions

- Z Orientation
  - Allowable stress for 100,000 hr service life at 700°C is 5-10% lower than cast Inconel 738LC
- XY Orientation
  - Allowable stress for 100,000 hr service life at 700°C is 51% lower than cast Inconel 738LC
- Allowable stresses are still sufficient to build the designed impeller and survive creep.