Design of a pressure cell for 1 GPa heat treatments of ferropnictide ($BaFe_2As_2$) superconductors

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Abstract:

Critical current density (J_c) in ferropnictide wires is shown to increase as heat treatment temperature decreases, illustrated in Figure 1. Below 550°C however, J_c decreases as a result of the material's low density, where voids present in wires act as insulators that block off current. The focus of this project is to design a pressure cell capable of exerting 1 GPa of pressure on a ferropnictide sample at 550°C. The added pressure will help increase the density of the material, thus enhancing its superconductive properties.

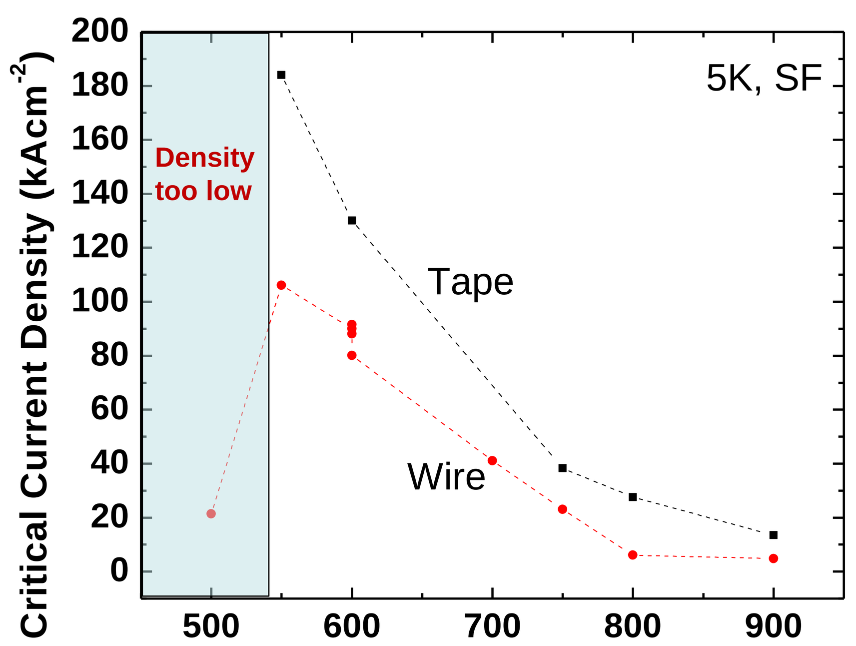

Fig 1. Critical current density as a function of heat treatment temperature. All heat treatments done at 200 MPa

Primary Objectives:

- Design a small pressure cell capable of heat treating samples at 600°C under 1 GPa of pressure
- Pressure cell must be able to:
  1. Withstand stresses due to applied load of 1 GPa at room temperature
  2. Withstand additional thermal stresses that develop at higher temperature due to thermal expansion
  3. Resist creep deformation

Results:

Table 1. Safety factors for stresses on various components (stresses at 600°C)

Type of stress	Component	Safety Factor
Axial stress	Push rods	2.38
Hoop stress	Body	1.35
Radial stress	Body	1.53
Hoop stress	Insert	1.67
Radial stress	Insert	1.41
Axial stress	Screws	3.12
Shear stress	Screws	1.80

Pressure cell design and components:

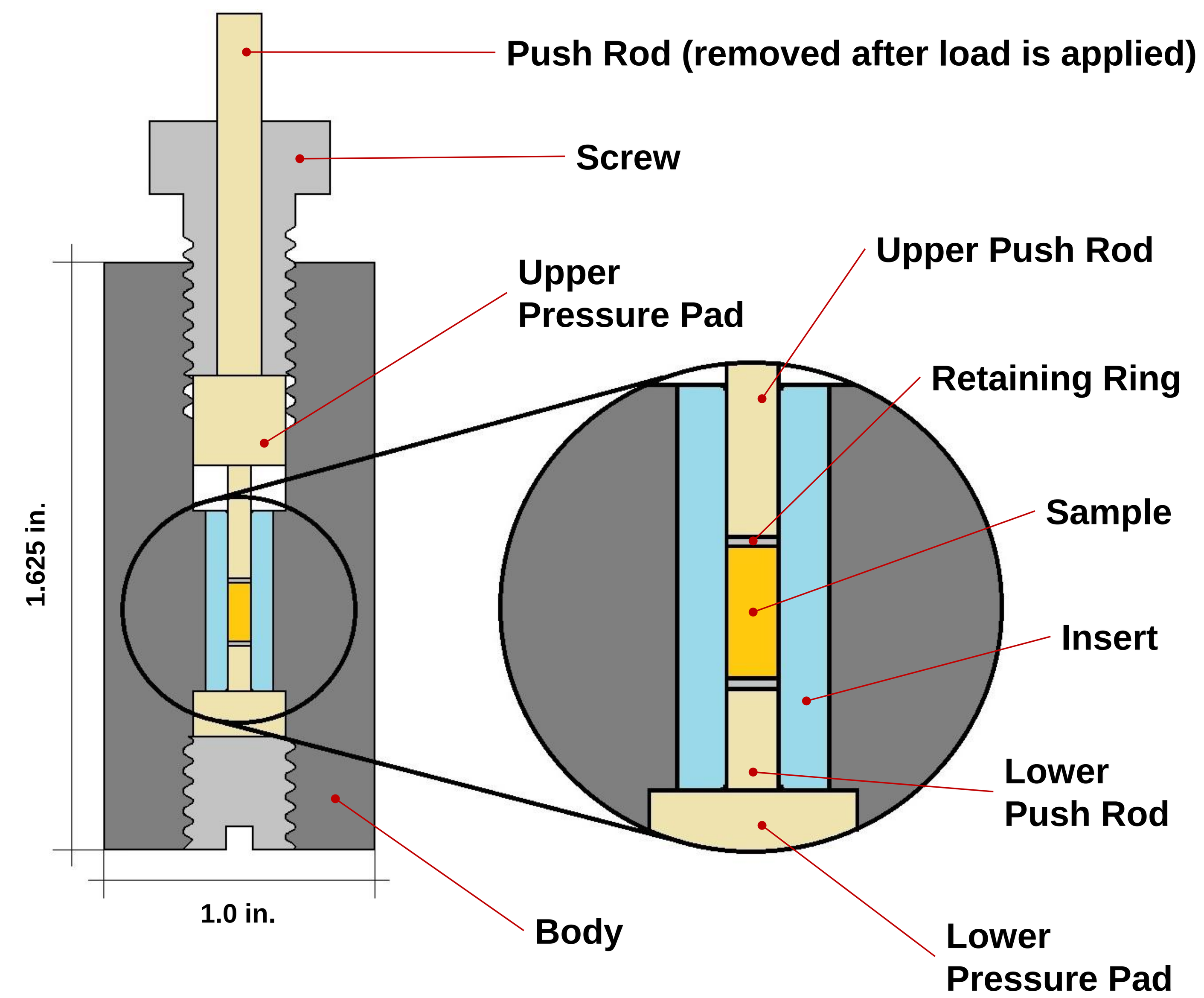

Fig 2. Cross section view of pressure cell

Material selection and design:

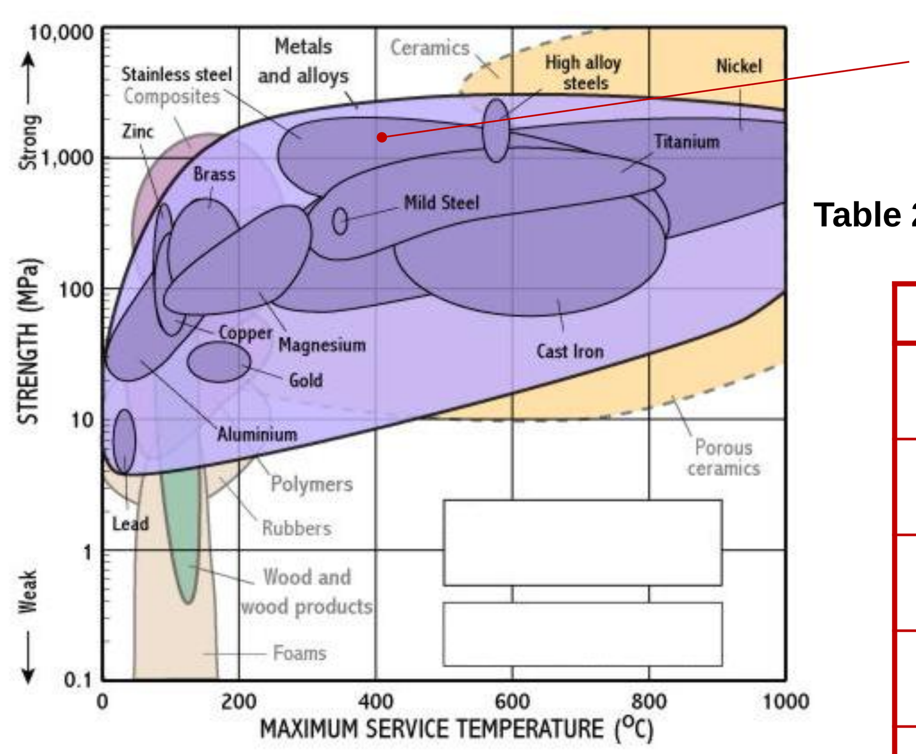

Fig 3. Strength of various materials at maximum service temperatures (http://www.materials.eng.cam.ac.uk/mpsite/interactive_charts/strength-temp/NS6Chart.html)

Stainless steels were chosen given their high strengths at a wide range of temperature and their relative ease of machining

Table 2. Material selected for each component

Component	Material
Body	410 Stainless Steel
Screws	410 Stainless Steel
Push Rods	Tungsten Carbide
Pressure Pads	Tungsten Carbide
Insert	M4 Steel
Retaining Rings	17-4 PH Stainless Steel

Considerations:

- Body must be strong enough to resist hoop stress but must be ductile enough to not shatter if failure occurs
- Screws and body must be made out of the same material to avoid additional thermal stress in between threads
- Insert must be hard enough to resist possible scratching from push rods

Critical stresses when under load:

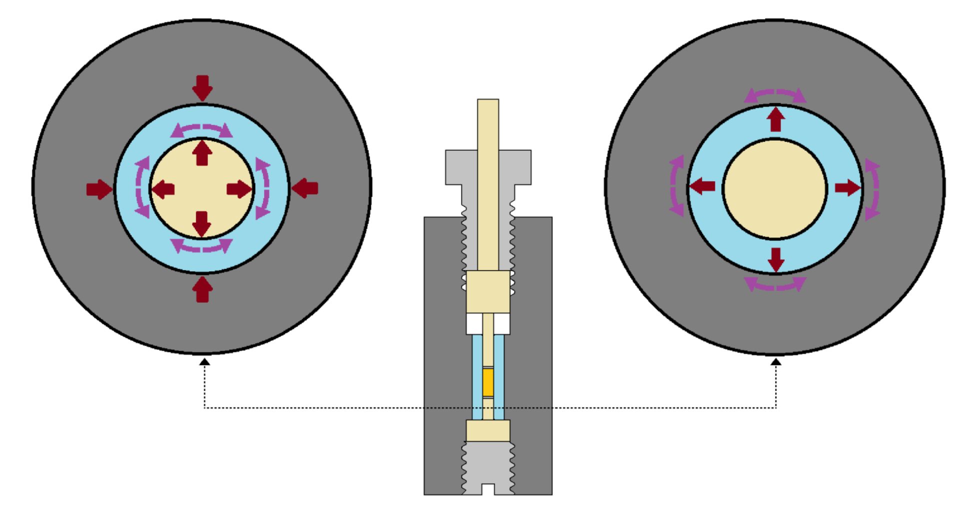

Fig. 4 Hoop stresses (purple) and radial stresses (red) on insert (left) and body (right)

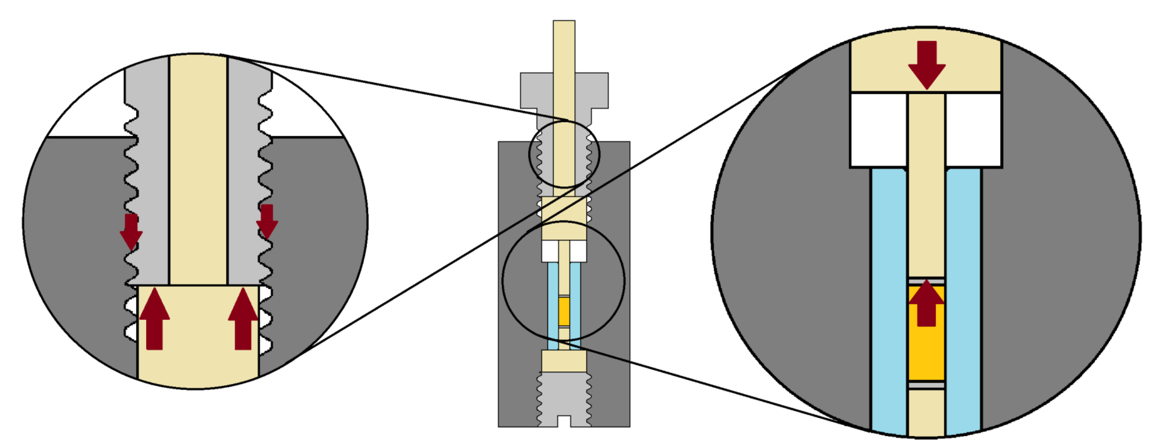

Fig. 5 Axial stresses on screw (left) and axial stresses on push rod (right)

Assumptions for stress analysis:

1. Stresses on body and insert were modeled as stresses on pressurized thick walled cylinders
2. For material properties at 600 °C:
   A. Coefficients of thermal expansion at 600 °C were found through material data sheets
   B. Yield strength at 600 °C was estimated to be half the yield strength at room temperature (estimation based on data of similar steels)
   C. Modulus of elasticity was assumed to remain unchanged

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