Carbon Fibers from corn stover lignin

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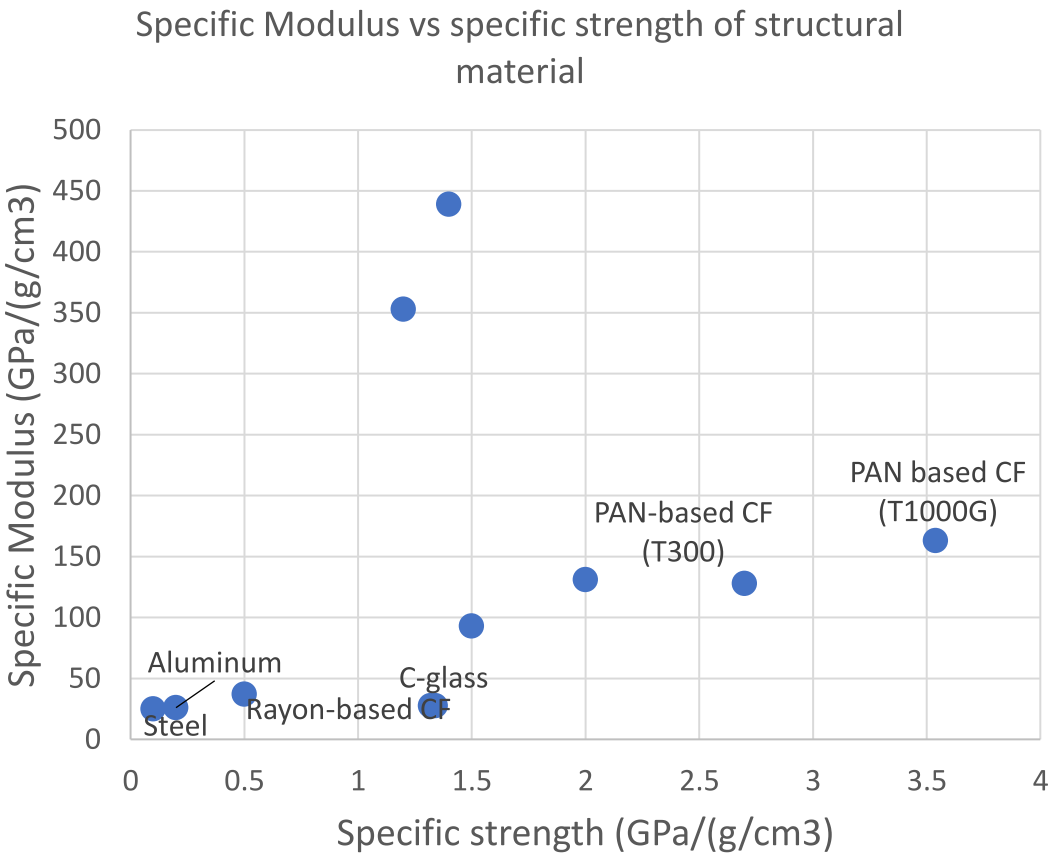
Introduction: carbon fibers

- High specific strength (approx. 2-3 GPa/(g/cm^3)) and modulus (approx. 150-300 Gpa/(g/ cm^3))
- Twice as much weight-savings compared with glass fiber-reinforced composites
- Thermally and electrically conducting (up to $4x10^5$ S/m)
- In contrast glass fibers are insulating (10^{-12} S/m)



Morgan, P. (2005). Carbon fibers and their composites (CRC Press).
Peebles, L.H. (2018). Carbon fibers: formation, structure, and properties (CRC Press).

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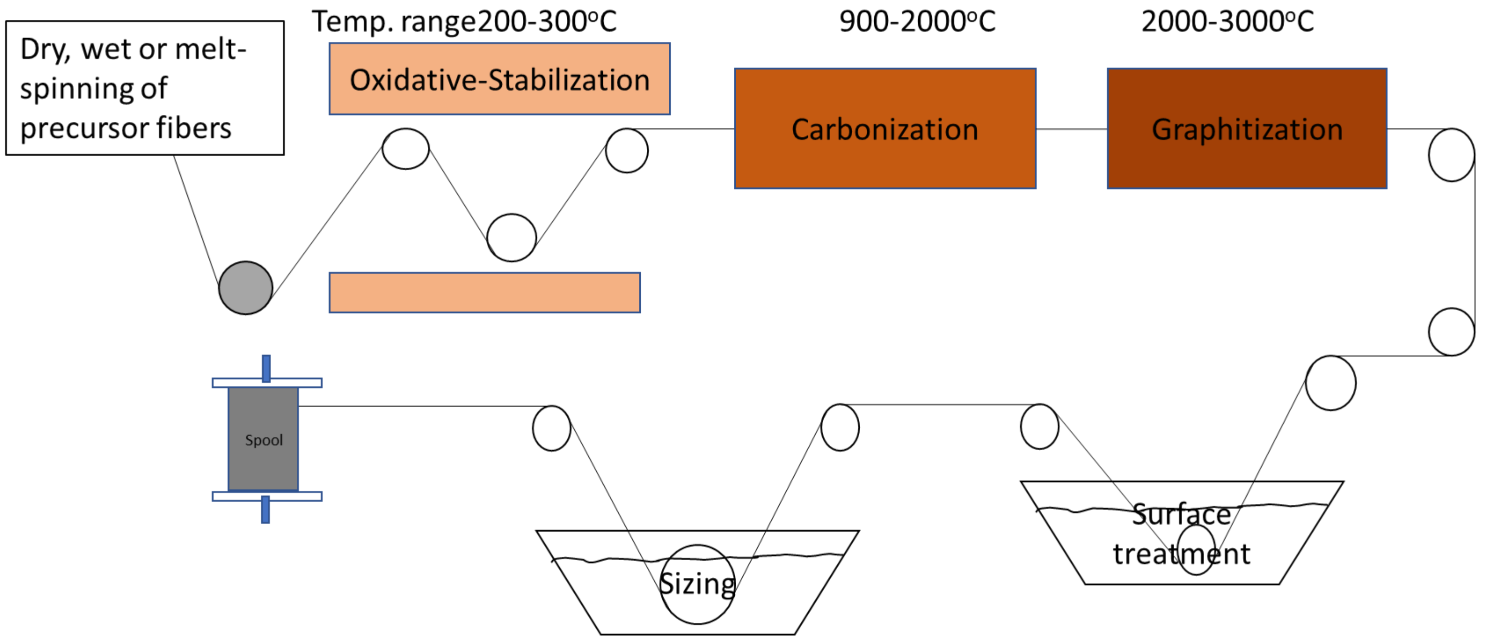
Carbon fiber processing steps

- Carbon does not melt or dissolve in any solvent
- hence carbon fibers must be produced using precursor fibers.
- Three primary steps in processing
    1. Fiber spinning : Dry, wet or melt spinning
    2. Stabilization : render fiber infusible
    3. Carbonization : remove almost all non-carbonaceous elements



Schematic of carbon fiber production

Kanhere, S.V., Bermudez, V., and Ogale, A.A. (2021). 11

Literature review: carbon fiber precursors

- Required characteristics of carbon fiber precursors:
  - ➢ Spinnable into fiber form
  - ➢ Crosslink to form infusible fibers
  - ➢ Reasonable carbon yield of stabilized fibers
- More than 90% of the carbon fibers in current market are PAN-based carbon fibers
- Precursor must be pure and narrow

Carbon fiber precursor	**Tensile strength* (GPa)**	**Tensile modulus* (GPa)**	**Electrical resistivity * (μΩ.m)**
[redacted]			
Mesophase pitch	2-3	400-750	2-3
[redacted]			

*Morgan, P. (2005). Carbon fibers and their composites (CRC Press)

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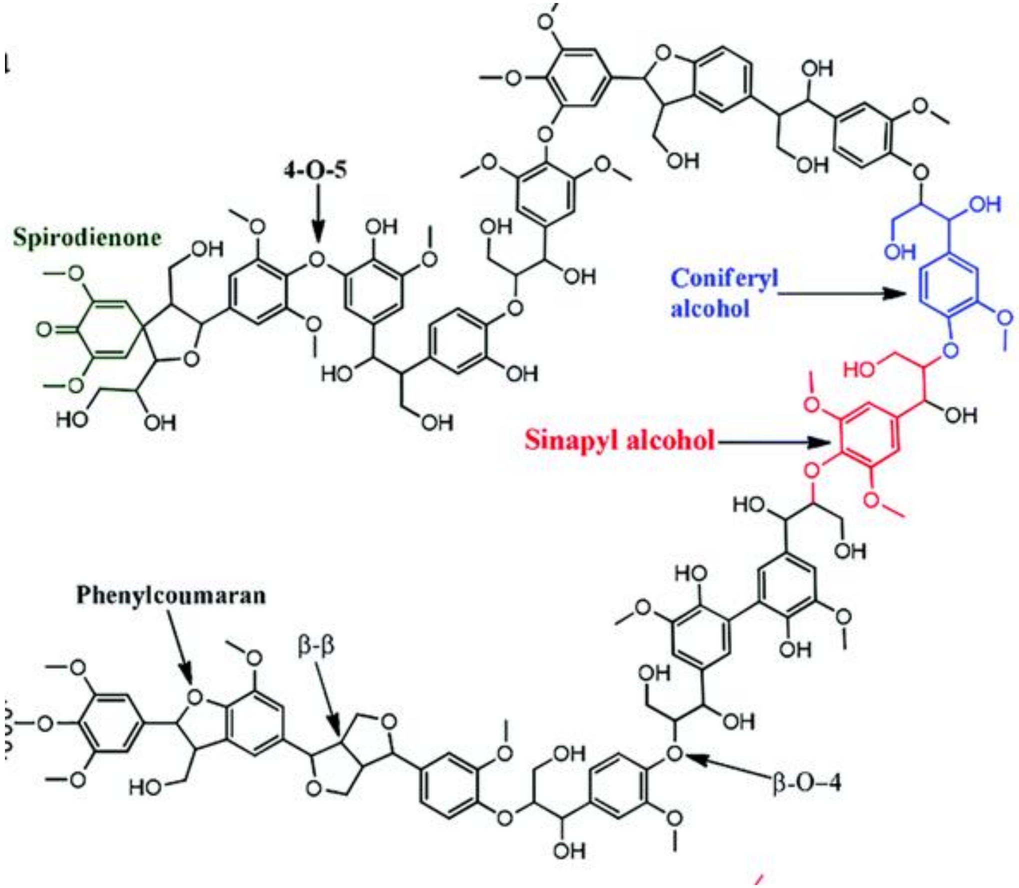
Lignin : Carbon fiber precursor ?

- Extracted from biomass by breaking covalent bonds with cellulose
- Three sources
    1. Softwood (e.g. Southern pine)
    2. Grass (e.g. Corn stover)
    3. Hardwood (e.g. Hybrid Poplar)
- Structure depends on the source, extraction and fractionation method
- Has relatively high aromatic phenolic moieties as compared with rayon



Representative lignin structure

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Ogale, A.A., Zhang, M., and Jin, J. (**2016**). JAPS *133*
W.-J. Liu, H. Jiang, H.-Q. Yu, Green Chemistry 17 (**2015**) 4888–4907

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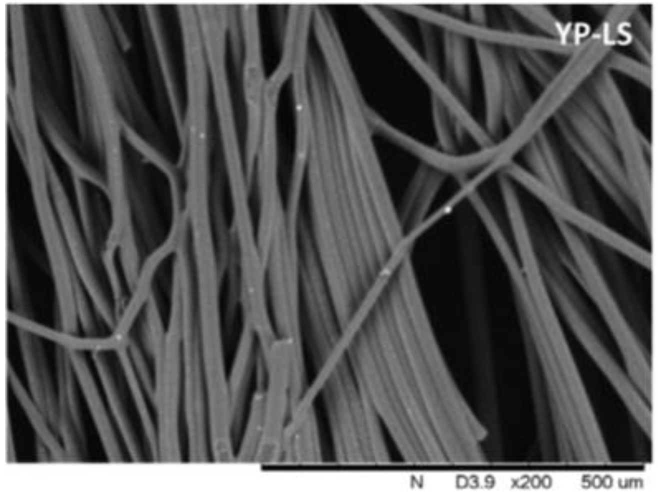
Lignin-based carbon fibers

- Most of the lignin fibers have been melt-spun in literature
- Attwenger et al. (2014) highest melt-spun neat hardwood lignin-based CF strength is 0.67 GPa from organosolv tulip poplar
- Qu et al. (2018) melt-spun corn-stover lignin, took 40 hrs to stabilize and resulting carbon fibers have tensile strength of 0.45 GPa
- Properties of resulting carbon fibers are poor due to fiber fusion during stabilization or defects in carbon fiber



Fibers fused during stabilization (Hosseinaei et al.)

Qu et al. (**2018**). JAPS 135, 457361
Hosseinaei et al. (**2016**). ACS Sus Chem. Eng. *4*, 5785–5798
Attwenger, A. *Masters thesis* (University of Tenessee-Knoxville (**2014**))

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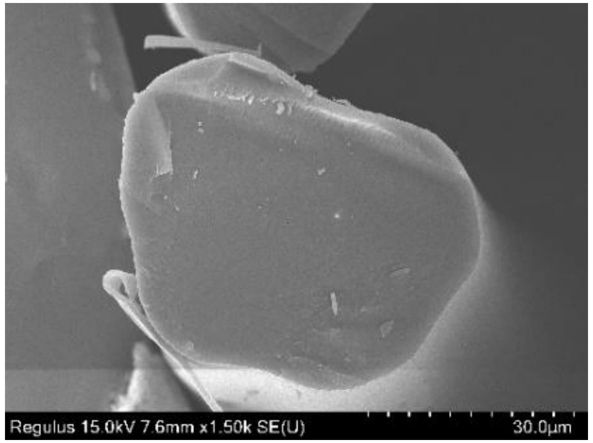
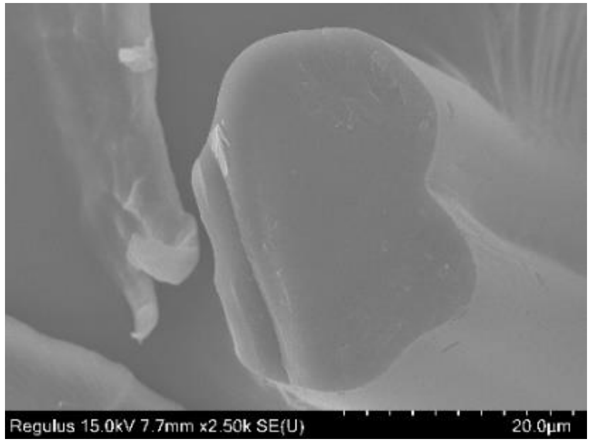
Dry-spinning : Solution temperature

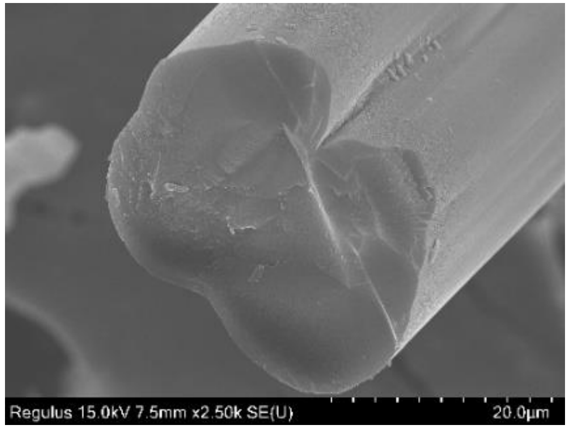
- Spinning temperature between 50-70°C
- At temperatures above 70°C, solvent starts flashing interrupting the extrusion, but fibers develop cracks on the surface



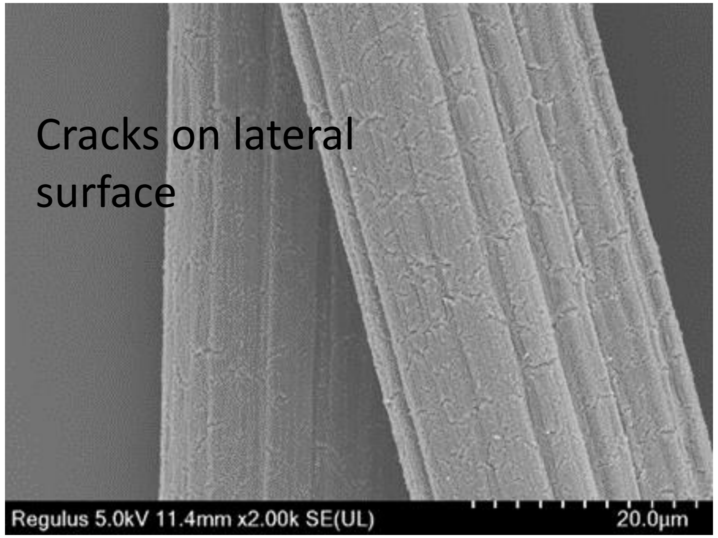
Solution temperature
57°C



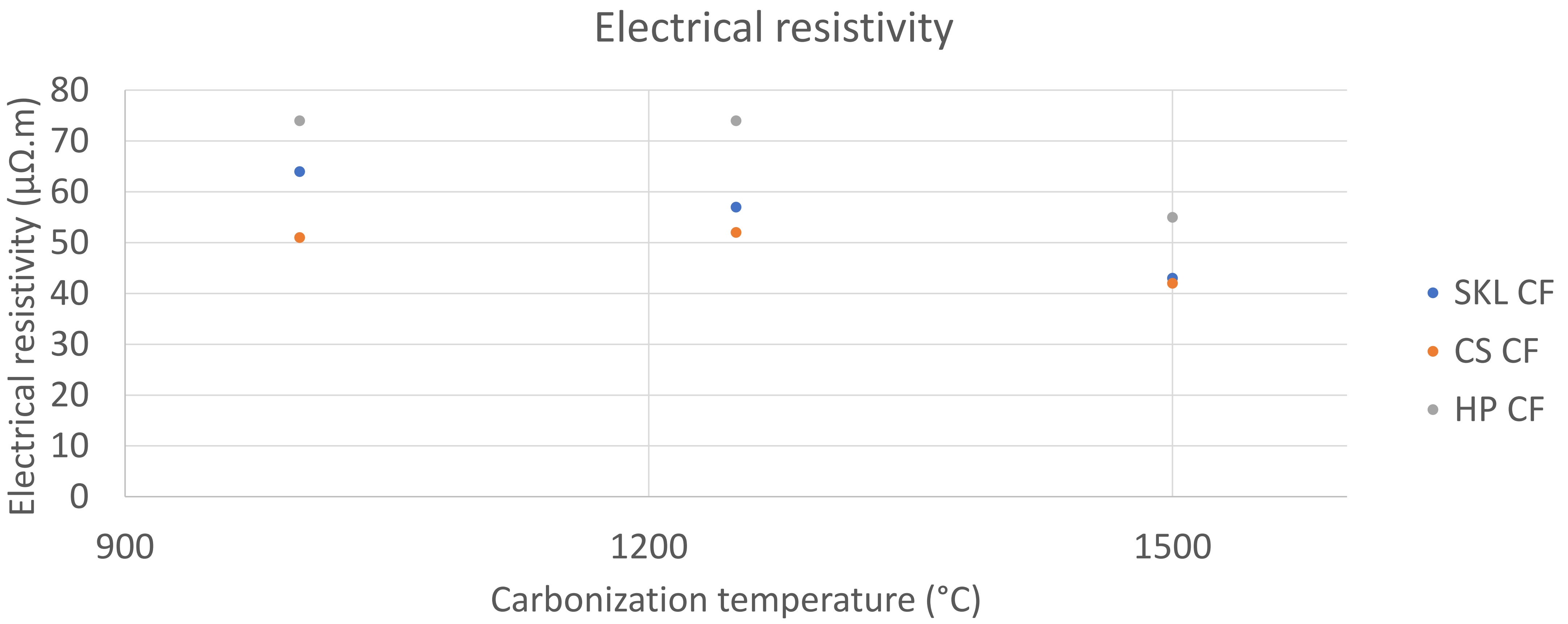
62°C



67°C



75°C



Electrical resistivity
Electrical resistivity (μΩ.m)
80
70
60
50
40
30
20
10
0
900
1200
1500
Carbonization temperature (°C)
SKL CF
CS CF
HP CF