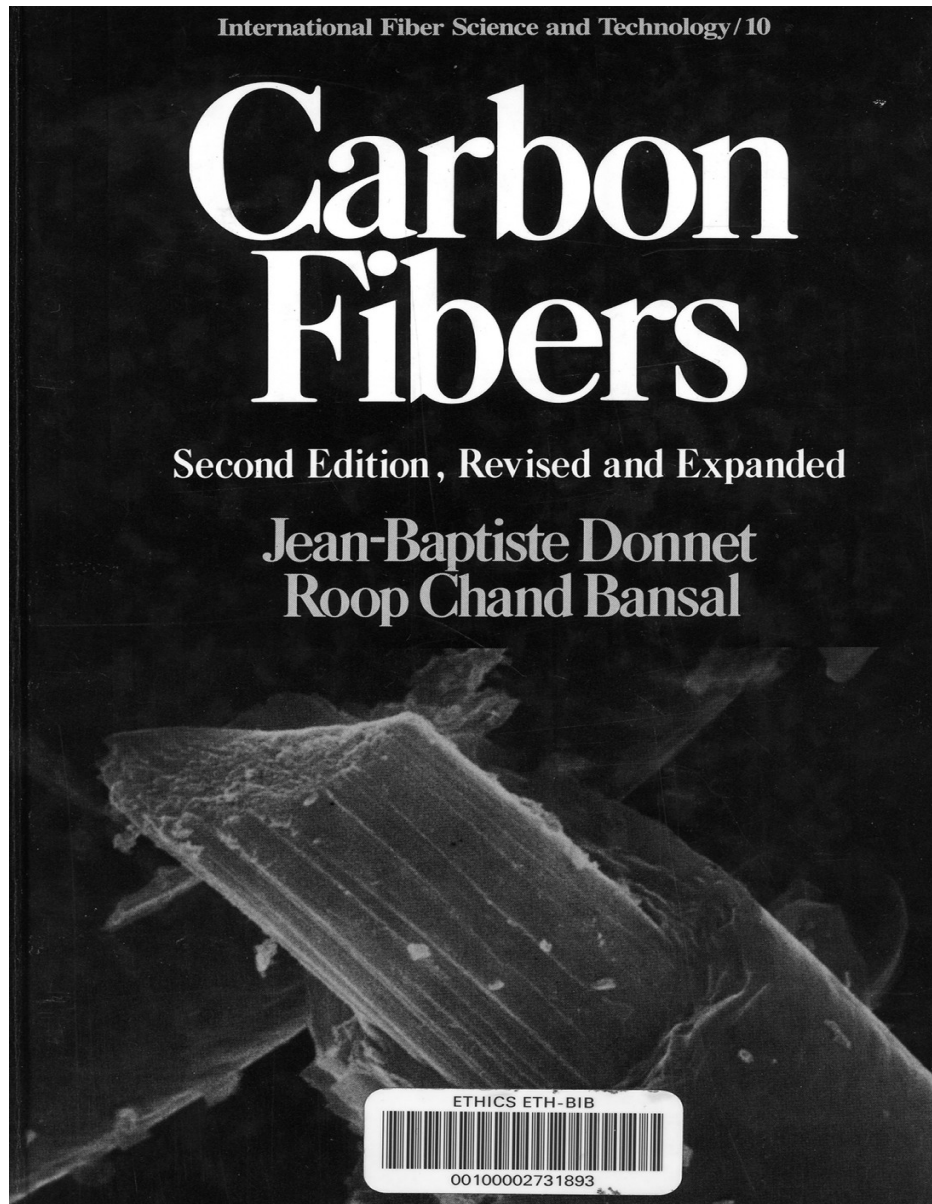


# Carbon fibers

based on book of Jean-Baptiste Donnet and Roop Chand Bansal



Carbon fibers are made of extremely thin fibers made of carbon crystals aligned parallel to the long axis of the fiber. This orientation makes the material strong.

They were re-discovered in 1958 by dr. Roger Bacon (USA), but already Thomas Edison used them for electric bulbs (before tungsten).

This book does not contain information about temperature-dependence of tensile strength and modulus of elasticity for the temperature range of interest, I couldn't find this information elsewhere.

3<sup>rd</sup> edition of the book is being bought by CERN library

# Carbon fibers

production and classification

They can be obtained from many materials but in modern industry the most used precursor is polyacrylonityle (PAN). Other materials: rayon, pitch...

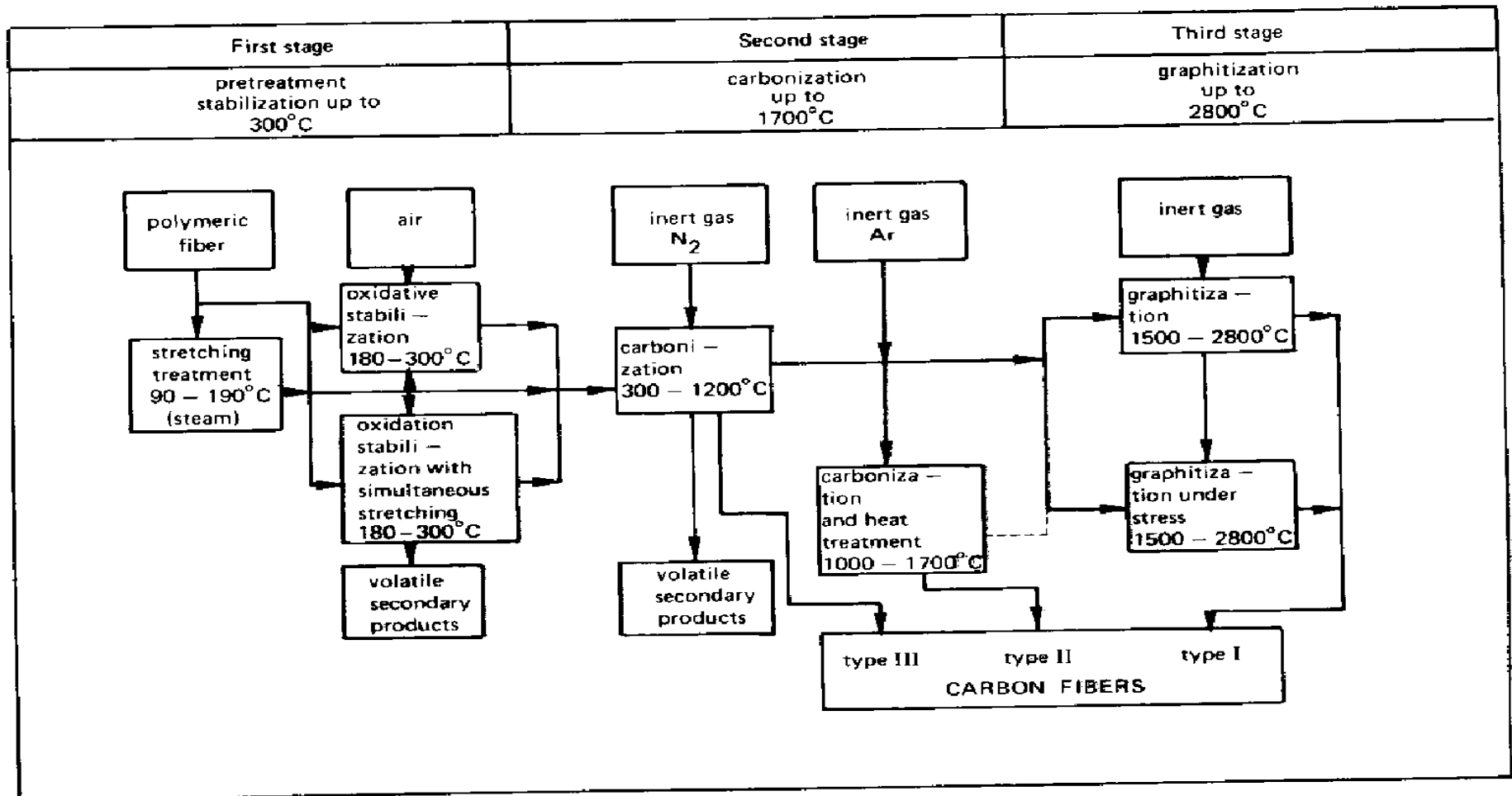


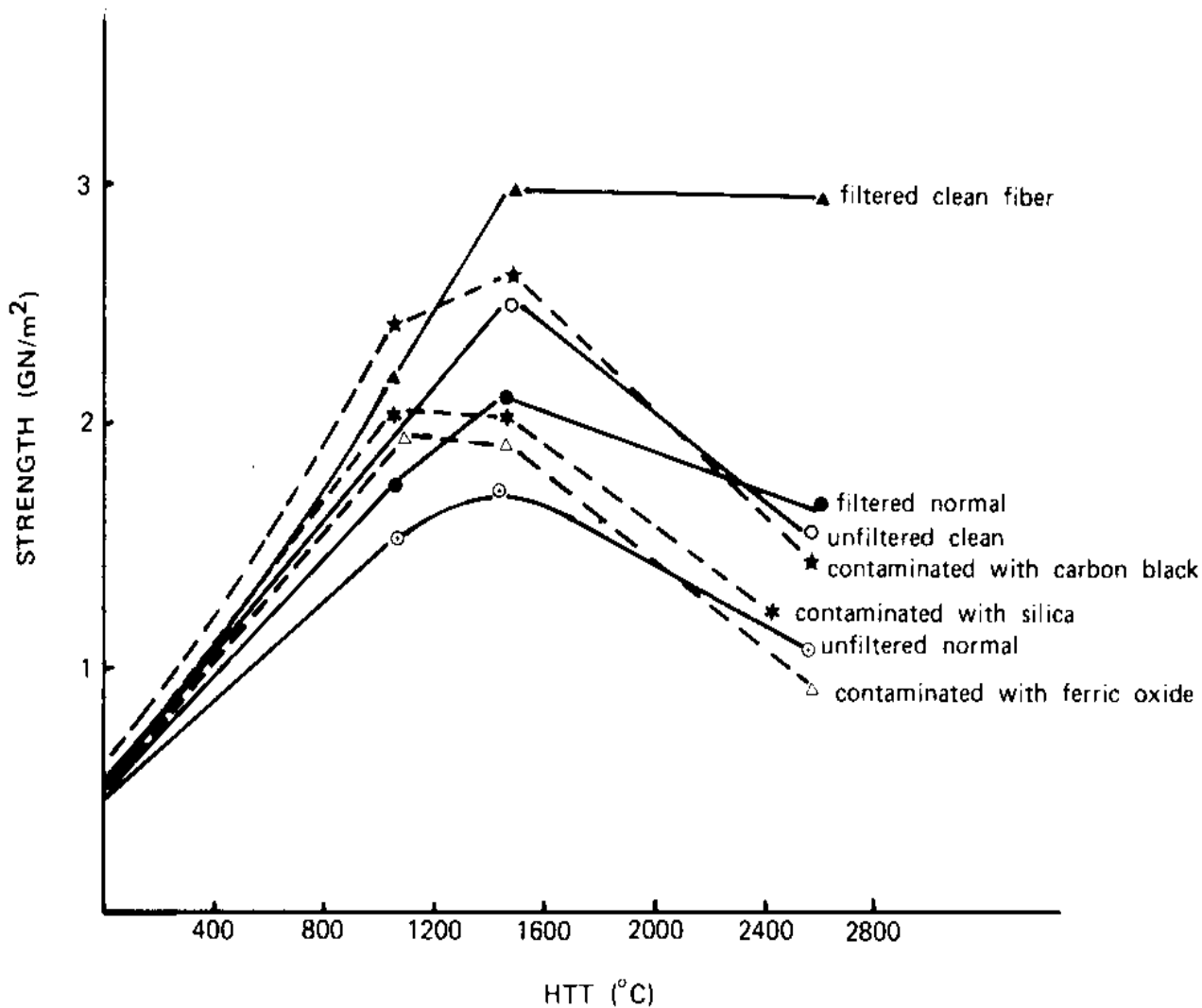
Figure 13 Schematic representation of carbon fiber preparation from PAN.

# Carbon fibers

tensile strength of various types

Definition: “The tensile strength of a material is the maximum amount of tensile stress that it can be subjected to before failure.”

Max about 3 Gpa

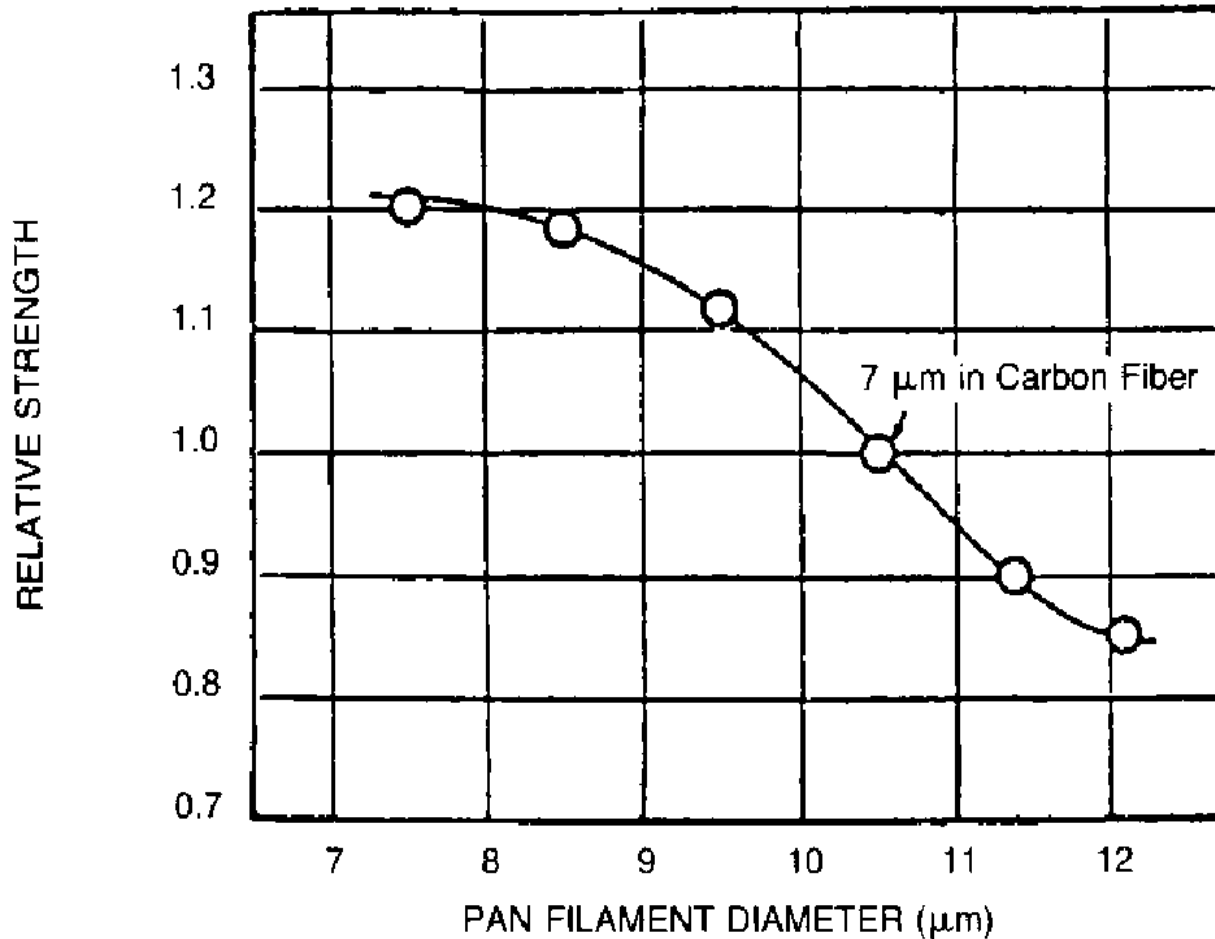


There is a study suggesting that the compression strength decreases with HTT

Figure 10 Strength of PAN-based carbon fibers as a function of heat treatment temperature. (From Ref. 72.)

# Carbon fibers

tensile strength as a function of diameter



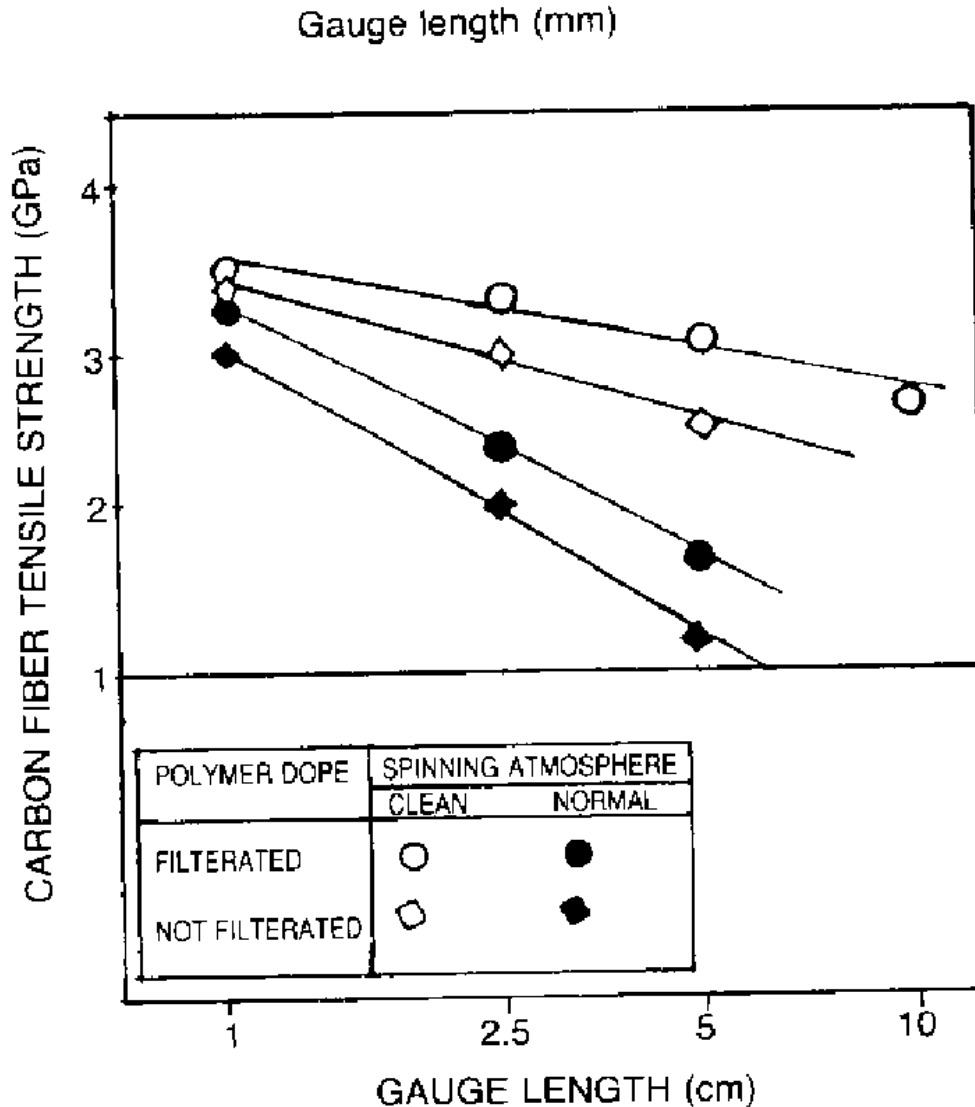
Two possible reasons:

1. defects - volumetric effect
2. minimization of the carbon core which contains less-oriented crystals therefore is weaker

Figure 3 Relationship between diameter of carbon fiber and strength.

# Carbon fibers

tensile strength as a function of length



Longer length – more defects along the fiber and the largest defect normally defines the strength of the whole fiber (not in our case!)

## Summary:

1. for PAN carbon fibers reaches maximum for HTT of about 1500 C (but some studies suggest higher T)
2. the stress during oxidation increases strength (optimum value exists),
3. also the atmosphere during oxidation plays role (air better than oxygene)
4. precursor fiber properties
5. strength is better for shorter fibers
6. larger diameter = smaller strength
7. neutron irradiation increases strength
8. flaws and defects decrease strength (21 GPa – graphite whiskers): etching to eliminate surface flaws

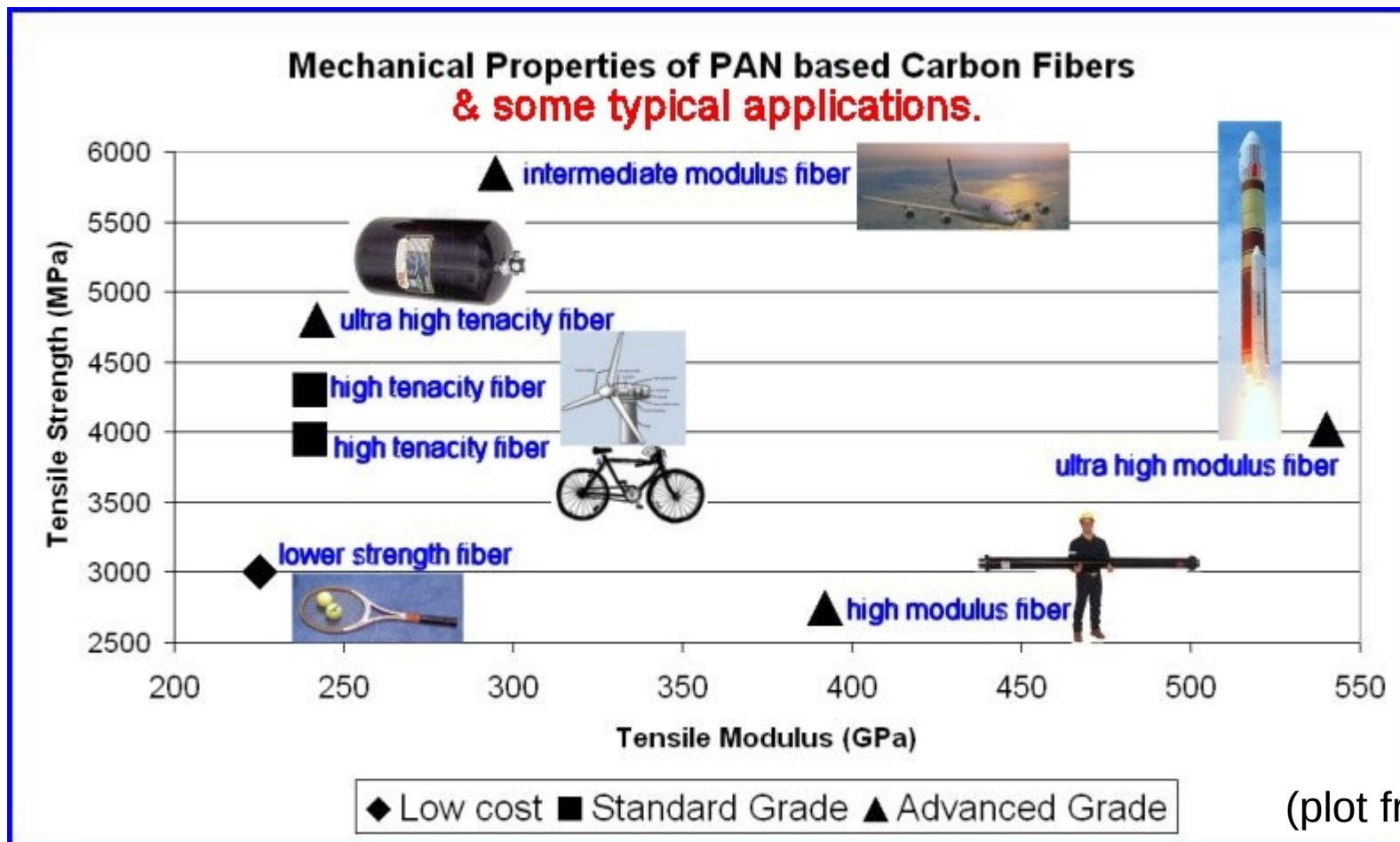
Figure 2 Relationship between gauge length and strength of carbon fibers.

# Carbon fibers

modulus of elasticity

Moduli of elasticity of carbon fibers seem to be a direct function of degree of preferred orientation (with respect to fiber axis)

Typical values 100-550 GPa.



# Carbon fiber for Wire Scanner

there are 2 sources of stress:

- a) momentum transfer from the beam – transverse to the wire long axis  
(likely small for LHC-beam)
- b) stress due to thermal expansion of the spot punctually heated by the beam  
(compression stress, tensile strength =? compression strength,  
pre-stress is factor 10-20 smaller than tensile strength)

Linear expansion coefficient  $\alpha$  for graphite is about 2% (from [1], for graphite: depend on direction) for 3800 K

Linear expansion produces compression stress due to Hooke's law

Small  $E$  = small stress, high tensile/compression strength = more difficult to break

$$\sigma = \Delta T \alpha E$$

But: the speed of sound in graphite  $v = 2.3 \cdot 10^5$  cm/s, therefore typical stress relaxation time is  $\text{BeamSize}/v$  ie. About 100 ns which is 5000 times shorter than heating time during the scan.

[1] Y.S.Touloukian, et al. "Thermophysical Properties of Matter"

# Carbon fiber for Wire Scanner

## summary

We do not need to maximize tensile strength at high temperature. Modulus of elasticity should be small, so it does not produce strong stresses (to melt carbon a 10 MPa is needed)

Therefore we need intermediate modulus fibers, probably 7 microns or so. A special kind with proper HTT, etching etc. should be used to optimize Wire Scanner performance.

Points:

- o) with fiber of 7 microns instead of 30 microns we decrease the energy deposited in the downstream magnets by factor ~ 15.
- o) coefficient of thermal expansion can also be optimized

Manufacturers/researchers should be contacted? Still no answer from prof. Donnet, another specialist contacted