Headstart Engineering Summer School 2017

Materials under Stress

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Outline

Materials in Structures under Stress

• Liberty Ships
• Catamaran - Team Philips
• Pole Vaulting
• Casing of an Aeroengine
• Shape Memory Cardiovascular Stents
Fracture of Liberty Ships

- 2nd World War
- Built in 57 days

- first all-welded ships
- 200 km of welded joints
- ~ 2,700 such ships built
- ~ 400 ships suffered “major” fractures

http://www.skylighters.org/troopships/libertyships.html

https://encrypted-tbn2.gstatic.com/images?q=tbn:ANd9GcQhe2PPxSPtE0axTm1IESek6NO9rzV5cgjjsQrKnsQ
Launch of Team Philips
Totnes, Jan. 2000

Largest catamaran in the world, made entirely from carbon fibre composite

http://www.petegoss.com/gallery.php?t=team-philips&gID=26

http://scillymemories.co.uk/gallery/00s/2000-pete-goss-and-team-philips/
Loss of Team Philips due to fracture of port hull

Off Scilly Isles, Mar. 2000

http://scillymemories.co.uk/gallery/00s/2000-pete-goss-and-team-philips/
Fracture toughness: resistance of a material to crack propagation
Yield stress: stress at which plastic deformation first occurs
Izod apparatus for measurement of the energy absorbed during fracture (https://www.doitpoms.ac.uk/)

Fracture toughness is often measured by the energy absorbed during an impact test.
Izod apparatus for measurement of the energy absorbed during fracture (https://www.doitpoms.ac.uk/)

Polymer - Acrylic

Metal - Copper
Fracture Event in Liberty Ships

- 16th January, 1943
- Portland, Oregon, USA
Fracture Event in Liberty Ships

SS Schenectady

• 16th January, 1943
• Portland, Oregan, USA

Constance Tipper (1894-1995)

• NST 1915 (one of first women)
• CUED 1929-1960
• Showed that Liberty Ships failed because of brittleness of the steel at low temperatures

http://www-g.eng.cam.ac.uk/125/1925-1950/tipper.html
Strains in a vaulting pole under service conditions

\[ \theta = \frac{1}{R} = \frac{\varepsilon}{r} \]
\[ \therefore \varepsilon = \frac{r}{R} \]

unstrained

strained to curvature radius \( R \)
Sergei Bubka, who has broken the world pole vault record 35 times, in action with a composite vaulting pole.
SEM micrograph of the fracture surface of a fibreglass composite, showing extensive fibre pull-out

https://en.wikipedia.org/wiki/Fiber_pull-out
Energy absorption due to fibre pull-out during fracture of an aligned composite.

\[ G_{cp} = 4f \tau_{i*} r s^2 \]

\( s = x_0 / 2r \)
Trent 800 engine on a Boeing 777

http://news.bbc.co.uk/1/hi/business/1606289.stm
Video clip showing a RR fan blade containment test for an aeroengine casing
Stress in a pressurised thin-walled tube

Many components & structures in this condition: Boilers, pressure vessels, pipelines, blood vessels, submarines, aircraft & spacecraft

\[ \sigma_z = \frac{Pr}{2t} \]

Axial stress

\[ \sigma_h = \frac{Pr}{t} \]

Hoop stress

\[ F = (2\pi rt)\sigma_z \]

\[ F = (\pi r^2)P \]

\[ F = (2rL)P \]

\[ F = (2tL)\sigma_h \]
Stress distribution in a large aircraft (Airbus A380)

- Stress states in the fuselage and wings
- $\Delta P \sim 0.6$ atm
- Max. weight $\sim 560$ tonnes
- Length $\sim 70$ m
- Fuselage diam. $\sim 7$ m
- Skin thickness $\sim 3$ mm
Smart Materials with Memory

• Materials for Cardiovascular Stents
What is a Stent?

Expandable mesh tube used to treat focal narrowings inside the blood vessels

The word is derived from the name of a British dentist, Charles Stent
Stents: Endovascular Repair

Arm insertion point

Groin insertion point

Minimally-invasive process
Balloon Angioplasty

Coronary Stents

Dilated balloon catheter and stent

Plaque

Stent deployed
Classification of Stents: Deployment Method

**Balloon expandable Stents**

- Stent in its original shape
- Stent compressed to fit within the balloon catheter
- Stent deployed by inflation of balloon
- Expanded stent

Balloon expandable stents are permanently deformed.
Self-expanding Stents – *Shape Memory Materials*

Stent in its original shape

Stent compressed to fit within the catheter and *constrained by a sheath*

Sheath is pulled back

Stent can recover its original shape – deformation is reversible
Self-expanding Stents – Shape Memory Materials

Demo
Shape Memory Effect
The Basics
All solids are made up of atoms: atoms are typically around 0.1-0.2 nm in diameter (1 nm = $10^{-9}$ m)

Co-operative motion of a large number of atoms relative to their neighbours
Shape Memory Effect

Material in the “trained” shape

deformation

Deformed material

heating

Material adopts “trained” configuration

cooling

Material retains its “trained” shape

low T phase

high T phase
Exploitation of Shape Memory Effect in Stents

1. Stent is “trained” to have a preferred shape.

2. The stent is compressed to fit within a catheter and constrained by a sheath while it is being kept cool (e.g. cold saline).

3. The catheter is then threaded through the vessel and, once in the desired location, retraction of the sheath allows the stent to expand and warm up to body temperature.
Shape Memory Effect - The “Ferris Wheel”

Demo