Materials 2 Questions set 8, Comments and answers
Durability and failure in materials – deformation, fracture & corrosion
Materials story: Challenger and Liberty ships – learning from mistakes

1. Watch the videos on Doitpoms of polymer balls bouncing at different temperatures, and silly putty being deformed at different rates:
http://www.doitpoms.ac.uk/tlplib/glass-transition/demos.php
(i) State carefully what you observe, and then explain the behaviour of the balls, and silly putty, use annotated sketches in your answer.

This question is covered comprehensively on the Doitpoms website in the same section as the videos.

Further comments:
Observations from watching the series of videos, including the close-up videos. The large-scale videos show the behaviour of the balls in terms of how much they bounce – with the maximum bounce being at room temperature, and the minimum at near the glass transition temperature (Tg), and somewhat surprisingly at the lowest temperature (well below the glass transition temperature) the ball then shows significant bounce *[when I showed these videos live in lectures there was a gasp when we got to the last video and the ball bounced higher at the lowest temperature]*. This high-bounce behaviour at low temperatures, well below Tg, is analogous to the behaviour of a steel ball bouncing on a steel anvil (see the video uploaded on learn). The close-up videos show the local deformation of the balls in more detail – significant deformation of the balls is seen in all cases from room temperature to the glass transition temperature. Well below the glass transition temperature the material behaves as a rather rigid glassy solid and no deformation is observed macroscopically. Tips for sketches: see answers to question set 4; and slides 29-37 in "Small scale structure-metals ceramics polymers-with links to practice-all slides-V2" from the Microstructure section of the course.

To explain the behaviour the dissipation of energy needs to be considered. Polymer deformation is viscoelastic.
- well above Tg most of the deformation is elastic and only a small proportion is viscous
- as the temperature decreases more of the deformation is viscous and less elastic
- near Tg much of the deformation is viscous and only a small proportion is elastic
- well below Tg the material is a rigid glassy solid it behaves elastically – there is no viscous dissipation of the energy from the deformation, and because the material is below Tg there is no significant movement of the polymer chains compared with the behaviour when the material is well above Tg.

(ii) In what applications in engineering is this behaviour important?
Any application where a thermoplastic polymer or an elastomer (rubbery polymer) may be used below its glass transition temperature, e.g. in a seal (as in the Challenger disaster), or in car tyres in cold conditions (see next question).

(iii) How does this link to the Challenger disaster, and was it a purely materials issue?

From a materials perspective:
As discussed in the Materials Story: the properties of polymers can change considerably with temperature; becoming brittle at low temperatures (below Tg) or high strain rates. From a materials perspective this is at the core of the Challenger disaster.

Explanation from Richard Feynman
https://www.youtube.com/watch?v=6Rwcbsn19c0
Feynman gives a striking, and simple but deep, example about why thinking about engineering and materials is important.
Richard Feynman was one of the top physicists of the last century. His research was in theoretical physics, and he was an amazing teacher and popularizer of science. He made awesome contributions to science, learning and had an approach that resonates strongly with me. Google more if you're curious – there are some great videos online.

…and was it a purely materials issue?
Put simply, no.
The engineers knew and understood well about the materials issues involved (related to Tg), they explained the materials and engineering aspects, and did their best to convey their concerns. But there was pressure to go ahead with the launch of Challenger from the organisational/management team.

There are other examples, which have resulted in awful outcomes, where engineers have known about and understood the engineering/materials in situations well, but others in the organisations have overridden their judgement.

In summary – knowing and understanding about engineering, including materials, matters – and that is the focus of much of your degree. But how critical thinking and engineering judgement is conveyed to others – and is included well in the final decision making matters. This depends on the people involved – how they communicate, listen, speak, and what they believe is important in terms of ethics. Some of these issues can be far from straightforward – especially around speaking up in an organisation/to someone higher in the organisation with different views.

2. Elastic bands and car tyres are both made from elastomeric materials. However, these two materials have different properties.
As stated in the original question: *To answer part (ii) of this question, and perhaps other parts, you will need to use* ***Resources*** *beyond what has been given on Learn to answer this question – recommendation start with Google.*

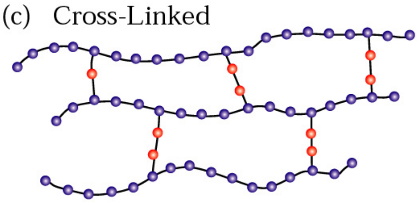
(i) State three key property requirements for rubber used in car tyres.
Here a several property requirements:
- good grip – in different conditions, e.g. in the wet, and perhaps in mud, loose surfaces, ice and snow
- that they can be manufactured
- good wear resistance
- resistant to degradation in UV light

- low noise when in use

(ii) Use sketches, and a few words, to explain the difference in the structures and constitution of the elastomers used for elastic bands and car tyres.

both sketches should show long chain molecules [dark blue atoms in image below]; elastic bands have far fewer cross links [red atoms in image below] compared with rubbers used in car tyres. In car tyre rubber the cross links are achieved by vukanisation using sulphur. “Rubber” for car tyres contains many other additions including: carbon black (for wear & UV resistance), silica, sulphur, wax, and oils.

(c) Cross-Linked



(iii) Explain why the concept of glass transition temperature is important for tyres used in cold climates. Is a lower or higher glass transition temperature desirable for use in cold conditions, and explain why?

A significant factor for good grip of tyres is having a high **real area of contact** between the rubber and ground (an elastomer/rubber below Tg will act as a rigid solid, hence have limited real-area of contact; while around or above Tg the rubber will be more compliant thus have a higher real area of contact). For winter tyres designed for cold climates a lower Tg rubber compound is used as it provides higher real area of contact in such conditions.

Thought experiment: an extreme way to visualise this – which may work for you – is to think of a “hard-wearing-blu-tac” tyre giving better grip than a glass or steel tyre. You can also link this to grip of the soles of different footwear.

However, if the Tg is too high the tyre will also lack grip and other properties will be compromised.

3. (i) Give two examples of fatigue failures in engineering.
There are many examples of fatigue failures below are two examples: railways (gauge corner cracking), and aircraft (the story of Comet aircraft)

Gauge corner cracking of rails
http://interfacejournal.com/archives/1229

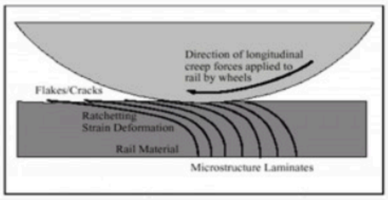


Figure 1. The ratcheting strain deformation of the rail — as longitudinal creep forces are imparted by tractive effort, braking, and longitudinal steering forces — causes plastic deformation and propagates crack initiation.

Figure 2. Reassembled rail from the 2000 Hatfield derailment.

Figure 3. A close-up of severe gauge corner cracking from one of the above rail sections. Image source: Train Derailment at Hatfield, A Final Report by the Independent Investigation Board, July 2006.

Further examples of gauge corner cracking of rails – note the similarities (initiation site – on the gauge corner, beach marks, rough regions of final fracture) and differences in the fracture surfaces.

http://www.iricen.gov.in
the fatigue initiated in the top left of the image

ResearchGate, Hiensch 2001
the fatigue initiated in the top right of the image

Comet jet aircraft

see article in the Structural Engineer: 2017, **95** (9)

Note – engineers who work with aircraft are typically aeronautical or mechanical engineers – but what was learned from these incidents is important to all engineers.

The Structural Engineer > **Archive** > **Volume 95 (2017)** > **Issue 9** > Beyond the limits of imagination: what do the Comet aircraft failures teach us?

Beyond the limits of imagination: what do the Comet aircraft failures teach us?

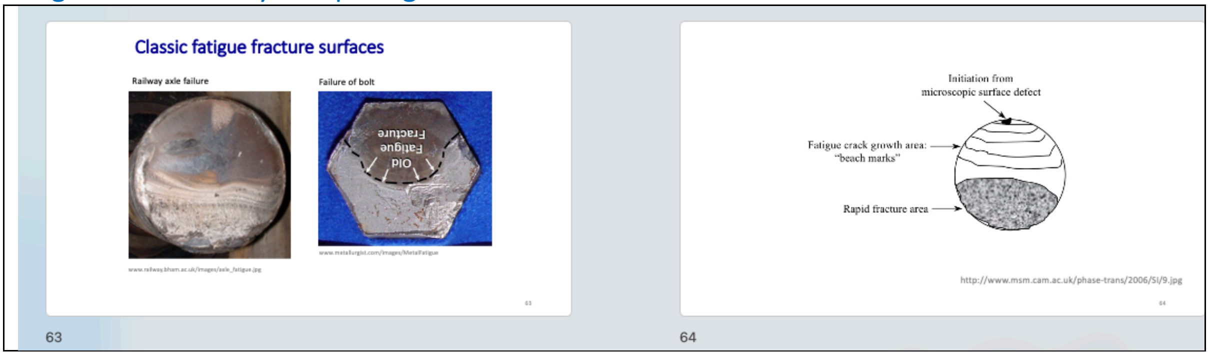
Sean Brady recounts the tale of the Comet jet airliner crashes of the 1950s and explains how the trailblazing accident investigation revealed a failure of imagination that holds lessons for all engineers.

Author(s): S. Brady

A key concept in fatigue is that it happens at loads well below the yield strength of the material – so if you create a design with only the maximum load in mind a component may break if it is subjected to repeated stresses.

(ii) What are the typical features of the fracture surfaces?

See Challenger Materials story-all slides-V1.pdf – you can understand the photographic images in slide 63 by comparing them with the schematic in slide 64



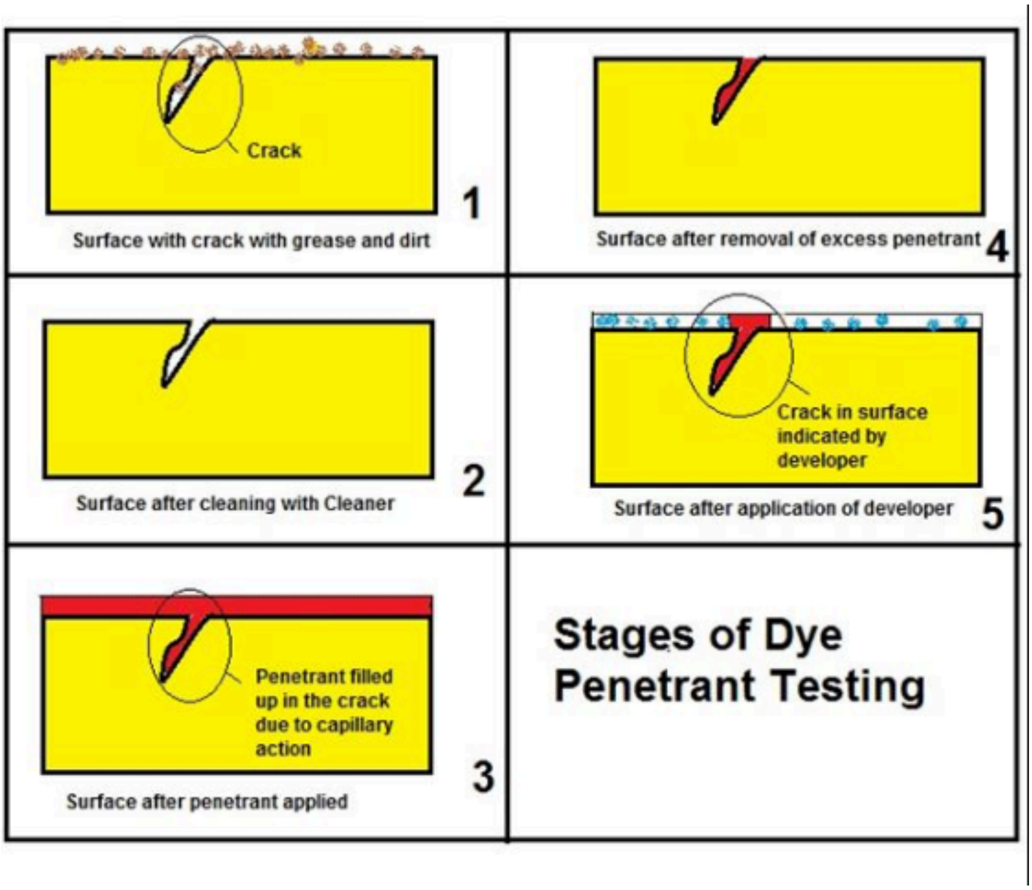
(iii) Dye penetrant testing can be used to examine a material / component for cracks. Draw a series of annotated sketches to explain the procedure.

as stated in question: You will need to use **Resources** beyond what has been given on Learn to answer this question – recommendation start with Google.

Dye penetrant testing can be used to examine a material / component for cracks.
A video of the process (NB PPE should be worn for the process)
https://www.youtube.com/watch?v=xEK-c1pkTUI

The process is straightforward and uses three aerosol cans.

series of annotated sketches to explain the procedure



(iv) Consider, and state, the locations in engineering structures and components where fatigue fractures may begin, with this in mind, what steps can be taken in engineering design to decrease the possibility of fatigue failures?

Fatigue often begins at the surface of a component, any stress concentrations (a corner that's not radiused), or cracks can act as starting points for fatigue to begin.

So

- radius corners
- shot peen, or shot blast, the surface (to create compressive stresses)
- use inspection methods to detect cracks before they lead to catastrophic failure

If cracks are detected – depending on the severity either continue to monitor or retire the component; another possibility is to grind or polish the surface to remove cracks

4. What is stainless steel?

Fe with a minimum of 11 weight % Cr

Why does it have good corrosion resistance (under most conditions)?

Because it forms a dense protective oxide layer. This happens because it oxides very easily.

Under what conditions does it have poor corrosion resistance?

Stainless steel generally has poor corrosion resistance in salt water environments (environments containing chloride ions).

Further basic information about Stainless steel

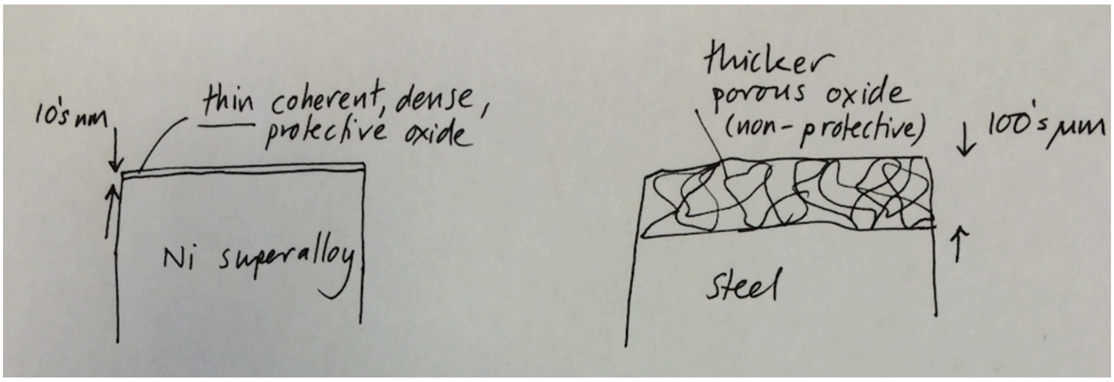
Steels: Microstructure and Properties, Fourth Edition, 2017, Harshad Bhadeshia and Robert Honeycombe, Chapter 12 - Stainless Steel, Pages 343-376

Abstract:

"A stainless steel is, in its raw form, resistant to stains, discolouration or loss of mass due to rusting. This is because it contains sufficient chromium to form a passive film of oxide on the surface, which isolates the substrate from the reactive environment. The film is able to reform in seconds in the event of damage. With an appropriate combination of alloying elements, stainless steels can be fully austenitic, a mixture of ferrite and austenite, fully ferritic or martensitic. They may or may not be precipitation hardened. The palette of alloys available permits considerable creativity in the application of stainless steel, from the facade of modern buildings, to artistic creations and in critical applications such as nuclear reactors."

To note: this book is an excellent textbook (**Resource**) on steels – it's not too long, and it's written by experts. The content is trustworthy and high quality [JB].

5. Draw annotated sketches to describe the formation of the oxide layer in: elevated temperature oxidation of a nickel superalloy (highly resistant to oxidation) and steel (which oxidises readily).



NB the oxidation behaviour of Ni superalloys, Al alloys and stainless steel are similar – all oxidise readily to form a thin, dense, coherent, protective oxide layer that prevents further oxidation. This behaviour is in contrast to metallic alloys that form non-protective oxide layers (e.g. steel), hence oxidation ("rusting") continues as there is no mechanism to stop it.

6. See slide below: What corrosion issues can you envisage when carbon fibre composites are used in contact with metals and alloys?
If the carbon fibre comes into direct electrical contact with metals/alloys it will set up a situation where galvanic corrosion can occur, this will be worse with metals that are less thermodynamically stable (more base/less noble in the slide).

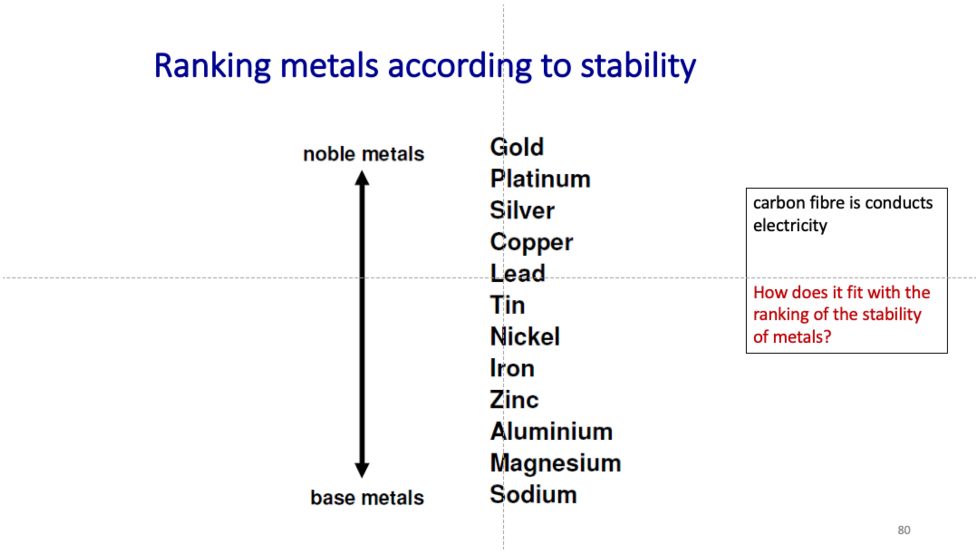
How can you mitigate these issues?
First by being aware that this may be an issue, particularly if an environment contains moisture/salts that will promote galvanic electrochemical corrosion.

If possible, avoid direct contact between the carbon fibre and the alloy, if the carbon fibre is surrounded by epoxy, so that it is only epoxy that is in contact with the alloy a galvanic couple will not be set up.

Use an alloy that is more stable is there is a likelihood that it may come into contact with carbon fibre.

Regular inspection/monitoring of the alloy for corrosion.

Core+/extra This webpage gives more information about the topic:
https://www.corrosionpedia.com/galvanic-corrosion-of-metals-connected-to-carbon-fiber-reinforced-polymers/2/1556



7. See slide below:
make an annotated sketch of what you would be able to see on the surface of the bolt.