ENMAT101A Engineering Materials and Processes
Associate Degree of Applied Engineering (Renewable Energy Technologies)
Lecture 3 – Mechanical Testing
# Mechanical Testing

<table>
<thead>
<tr>
<th>Reference Text</th>
<th>Section</th>
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<table>
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<th>Additional Readings</th>
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</table>
Mechanical Properties

Mechanical properties are relevant for engineering. Some examples;

<table>
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<tr>
<th>Mechanical Property</th>
<th>Test</th>
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<tbody>
<tr>
<td>Strength</td>
<td>Tensile / Compresssion / Shear</td>
</tr>
<tr>
<td>Stiffness</td>
<td>Slope of Stress-vs-Strain curve</td>
</tr>
<tr>
<td>Hardness</td>
<td>Rockwell / Brinell / Vickers / Shore</td>
</tr>
<tr>
<td>Toughness</td>
<td>Impact: Charpy / Izod</td>
</tr>
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Some properties can be measured easily (e.g. hardness), others may require breaking a specimen. (e.g. Ultimate Tensile Strength)
Destructive and Non-Destructive Testing

Destructive Testing requires destroying the specimen in order to measure the property. Often requires a specially prepared specimen. *(e.g. Tensile test).* Destructive testing is called mechanical testing.

Non-Destructive Testing (NDT) measures attributes of the specimen without damaging it. Does not normally need a prepared specimen. Typically used to find flaws inside a part. *(e.g. X-ray, Ultrasound)*
Destructive (Mechanical) Testing

Non-Destructive Testing (NDT) will be covered in later lesson. For now, the focus is on Destructive Testing, or Mechanical Testing, and follows directly from the textbook (Higgins).

1. Tensile Test (Higgins 3.2)
2. Hardness Tests (Higgins 3.3)
3. Impact Tests (Higgins 3.4)
4. Creep (Higgins 3.5)
5. Fatigue (Higgins 3.6)
6. Other Mechanical Tests (Higgins 3.7)

1. Tensile Test

- The tensile test pulls a test-piece until it breaks.
- Both force and extension are continuously measured.
- The specimen has thicker ends for attaching by grippers/collet/thread/shoulder.

*Tensile Tester: Wikipedia*
Tensile tests are usually done on prepared specimens.

A narrowed section is where the stress is calculated, otherwise the specimen will break where it is gripped.

“Necking” occurs on ductile materials after reaching the UTS.
“Cup and cone” fracture indicates ductility
Specimen Design

Specimen Design:

A. Threaded shoulder for use with a threaded grip
B. Round shoulder for use with serrated grips
C. Butt end shoulder for use with a split collar
D. Flat shoulder for use with serrated grips
E. Flat shoulder with a through hole for a pinned grip


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Force / Extension Diagram

Note the following: (Higgins 3.2.2)

- \( Y \) = Yield
- \( M \) = UTS
- \( B \) = Fracture
- \( B_1 \) = True Fracture
- Elastic / Plastic / Necking

Force-extension diagram for an annealed low-carbon steel: Higgins Fig 3.1.
**Convert Force to Stress**

**Stress** (MPa) = **Force** (N) / **Area** (mm²)

\[ \sigma = \frac{F}{A} \]

- **Tensile Stress**: Pulling
- **Compressive Stress**: Squashing
- **Shear Stress**: Sliding

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*Tim Lovett*
Mechanical test of the strength of mild steel.

Stress / Strain Curve for Mild Steel
Tim Lovett

EMMAT101A Engineering Materials and Processes
Mechanical test of the strength of mild steel.

**Stress / Strain Curve for Mild Steel**

*Tim Lovett*
Information that can be determined from the Stress/Strain curve…

1. Ductility
2. Elongation
3. Engineering strain
4. Strength
5. UTS
6. YS
7. Stiffness
8. Toughness

1. Hardness? Not directly, but correlates with strength. E.g. High strength steels are harder.

Stress / Strain Curve for Mild Steel showing elastic/plastic regions.
True stress (B) is higher than engineering stress (A). Due to decreasing area.

True Stress = Force / Actual area

Engineering usually based on original area because this will determine strength in service.

1 = UTS Ultimate Tensile Strength
2 = YS Yield Strength
3 = Engineering fracture Stress
4 = Work Hardening
5 = Necking

Wikipedia.
Strain

\[ \varepsilon = \frac{e}{L_o} \]

- Strain has no units.
- Low elastic strain in metals so should be a small number.
Strain Measurement: Extensometers

Strain in metals is very small, so precise measurement is needed – down to a micron or less. This is called an extensometer.

The clip-on extensometer shown above can measure accurately but is not intended to be left on during failure (breakage). Other methods such as feelers, lasers and cameras can be used to obtain data for the entire stress/strain curve.
**Clip-on Extensometer:**
Simple and precise, but fragile

**Laser Extensometer:**
Non-contact, reflectors

**Camera Extensometer:**
Non-contact, complex software

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Strain Measurement: Strain Gauge

A strain gauge glued to a test piece. Under stress, the steel will stretch and stretch the gauge with it. The resistance of the strain gauge will change as it stretches.

Strain Gauge glued to a steel test piece. 
http://www.doitpoms.ac.uk/tlplib/BD3/printall.php

EMMAT101A Engineering Materials and Processes
Strain Measurement: Strain Gauge

A strain gauge is a sensor attached to the surface of a part. The electrical signal representing strain can be converted to stress through Young’s modulus of the material.

Ductility: this is the ability of a material to deform without breaking.

The opposite to ductile is Brittle. (Like glass, ceramics)

Ductility allows forming processes (like pressing, wire drawing)

Measured as percent elongation: How far it has stretched compared to the original length.

\[
\% \text{ elongation} = \frac{L - L_0}{L_0} \times 100
\]
Ductile vs Brittle Fracture

An examination of the fracture surface of a tensile test piece can show whether the part was ductile or brittle.

**Cup-and-cone fracture in aluminum.**

Ductile specimen showing “cup-and-cone” failure, where shearing occurs at 45° to the applied force.

**Brittle fracture in a mild steel.**

Brittle specimen displays an almost flat fracture surface, perpendicular to the applied force.
Stiffness

\[ E = \frac{\sigma}{\varepsilon} \]

Many names:
- Young’s Modulus
- Modulus of Elasticity
- Stiffness Modulus
- Modulus!

• Usually a BIG number (GPa)

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<th>Tensile modulus (GPa)</th>
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<tr>
<td>80 to 1000</td>
<td>Engineering ceramics</td>
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Higgins 2.2.1 Table 2.1
Alternative to **Yield Point**

**Yield point.** A levelling off on the stress-strain curve as plastic deformation begins.

1. **True elastic limit:** The first hint of atomic slip. Hard to measure because some atoms move easily. Elastic.
2. **Proportionality limit:** End of straight line (Hooke's law). Still elastic.
3. **Elastic limit (yield strength)** Where permanent deformation begins. The lowest stress at which permanent deformation can be measured. This requires a manual load-unload procedure, and the accuracy is critically dependent on equipment and operator skill.
4. **Proof Stress (Offset yield point).** When a yield point is not easily defined.

Alternative Yield definitions for materials that do not exhibit a well-defined yield point.

Wikipedia
Proof Stress (Offset yield point)

Some materials do not show an obvious yield point. E.g. high strength steels and aluminium. In this case, an offset yield point is used, with an offset of 0.1 or 0.2% of the strain.

The real elastic limit…

You have an unknown material and a tensile tester. How do you find the yield point.

Note: “Proof Stress” is a British term, which is also used in Australia. Can also be called Yield Strength (US) or Offset Yield.
Tensile Test (Stainless Steel)

Extensometer attached but removed after the yield point determined.

This avoids damaging the sensitive extensometer when the metal breaks violently.

This test piece screws into the chuck.

http://www.youtube.com/watch?v=67fSwjYJ-E
Tensile test on 0.4% C steel in as-drawn state (work hardened).
Note the lack of obvious yield point, so using proof yield at point 1.
Note work hardening after releasing load.
Note hysterisis – increases with velocity showing up as curved elastic region.
Elongation is measured with an extensometer that clamps to the workpiece. Force is measured by a load cell on the tensometer (tensile test machine).
Calculation for Point 1:

Force: \( F = 19.8 \text{kN} \)

Area: \( A = \pi \times 6^2/4 = 28.27 \text{mm}^2 \)

Stress \( \sigma = F/A = 700 \text{ MPa} \)

Elongation: \( e = 0.192 \text{ mm} \)

Gauge Length: \( L_o = 25 \text{ mm} \)

Strain: \( \varepsilon = e/L_o = 0.0038 = 0.38\% \)

Stiffness (Modulus of Elasticity): \( E = \sigma / \varepsilon = 700/0.0038 = 182400 \text{ Mpa} = 182 \text{ GPa} \)
Calculation for Point 1:

Force: \( F = 19.8 \, \text{kN} \)

Area: \( A = \pi \times 6^2/4 = 28.27 \, \text{mm}^2 \)

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Stiffness (Modulus of Elasticity): \( E = \sigma / \varepsilon = 700/0.0038 = 182400 \, \text{MPa} = 182 \, \text{GPa} \)

Oops – went a bit too far!
Usually do Proof Stress for about 0.1 or 0.2% strain

Hmmm – bit low. Should be closer to 200MPa.
Steels
High strength steels have higher yield and UTS, but Modulus of Elasticity the same for all these steels:

A. Heat treated Cr/W alloy steel
B. Heat treated Ni alloy steel
C. Heat treated 0.62%C steel
D. Normalised 0.62%C steel
E. Normalised 0.32%C steel
F. Normalised 0.11%C steel

IMAGE: Byrnes, J. J,
*Testing and treatment of materials*
Various Materials
Stress/Strain diagrams for ceramic, steel and polymers.

a) Aluminium oxide
b) Low carbon steel
c) Rubber
d) Acrylic (hot)

Note that the strain scale for rubber has a different range.
Stress / Strain curves for various metals.

- SAE 1340 steel water-quenched and tempered at 700°F
- Stainless steel sheet 17-7PH
- Stainless steel (18-8)
- Annealed titanium alloy sheet (6A1-4V)
- Nickel alloy steel
- Annealed N-155 alloy sheet
- Bare aluminum alloy sheet (2024-T81)
- Alcoa 27ST
- Structural steel (mild steel)
- Magnesium
Structural steels all need ductility.

US steel grades shown here from A36 (mild steel) to A514 (high strength quenched and tempered structural steel. It is also only available in plate form.)

\[ 1 \text{ ksi} = 1 \text{ thousand psi} = 6.89 \text{ MPa} \]
Stress grades of bolts.

4.6 = 400 Mpa and 60% YS
8.8 = 800 Mpa and 80% YS
10.9 = 1000 Mpa and 90% YS
12.9 = 1200 Mpa and 90% YS

Higher grade bolts have lower ductility.

Grade 8.8 Bolt
Hebei Saite Fastener Co., Ltd.

Tim Lovett

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Comparison of Tensile Strength of Steels (UTS)

As steels get stronger they get more brittle.

American Iron and Steel Institute: AISI
Tensile Strength (UTS) values for different materials.

<table>
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</tr>
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<td>Elastomers</td>
</tr>
<tr>
<td>6 to 100</td>
<td>Woods parallel to the grain</td>
</tr>
<tr>
<td>60 to 100</td>
<td>Engineering polymers</td>
</tr>
<tr>
<td>20 to 60</td>
<td>Concrete</td>
</tr>
<tr>
<td>80 to 300</td>
<td>Magnesium alloys</td>
</tr>
<tr>
<td>160 to 400</td>
<td>Zinc alloys</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>250 to 1300</td>
<td>Carbon and low alloy steels</td>
</tr>
<tr>
<td>250 to 1500</td>
<td>Nickel alloys</td>
</tr>
<tr>
<td>500 to 1800</td>
<td>High alloy steels</td>
</tr>
<tr>
<td>100 to 1800</td>
<td>Engineering composites</td>
</tr>
<tr>
<td>1000 to &gt;10 000</td>
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Higgins 2.2.1 Table 2.1

Tensile Test on Plastic
Intertek Plastics: http://www.ptli.com
Wood

Wood is graded in terms of its tensile strength. F5 = 5 MPa, F7 = 7 MPa etc.

Some Kiln Dried hardwoods reach F27 grade.

Go to Wood Grading...
http://toolboxes.flexiblelearning.net.au

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Higgins 2.2.1 Table 2.1

http://harpertimber.com.au
Wood is so strong in pure tension that it almost never fails that way – because it is difficult to get enough grip. Instead, wood has always been tested in bending, and the result converted to a tensile force (at the bottom of the beam).

This image shows a 3-Point Bending test on a wood sample, used to determine the strength – called flexural strength.

Wood in a 3-point bending test: 
unm.edu
Wood

Comparing 3-point vs 4-point bending test. The 4PBT gives a region of maximum bending moment, rather than a point.
Stiffness

\[ E = \sigma / \varepsilon \]

Many names; Young’s Modulus, Modulus of Elasticity, Modulus!

*Stiffness: The stress that will stretch a material by a certain amount.*

Engineering materials frequently have a modulus of the order of 1000 000 000 Pa, i.e. \(10^9\) Pa.

This is generally expressed as GPa, with 1 GPa = \(10^9\) Pa.

### Higgins 2.2.1 Table 2.1

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2. Hardness

Resistance to indentation or abrasion. (no units)

There are several types of hardness tests:
• Brinell (Ball indentor. Measure diameter of dent)
• Vickers (Pyramid diamond indentor. Measure dent)
• Rockwell…

VICKERS: www.twi.co.uk
BRINELL: www.twi.co.uk
Rockwell Hardness Test

- Fast and simple test.
- Various scales for hard/soft materials

EMMAT101A Engineering Materials and Processes
There are many types of hardness test. Here are 3 indentor tests (Knoop, Brinell and Rockwell) and the Mohs scale that uses abrasion (scratching).
3. Impact

TOUGHNESS: 
Energy to break. (Joules)

Charpy Impact Test measures energy absorbed by impact and breaking of specimen.

A brittle material will hardly slow down the hammer, a tough material will almost halt it.

Toughness usually decreases at lower temperatures.

Toughness usually decreases with higher impact speed.

CHARPY IMPACT TEST: Tim Lovett
A tough material...
• resists a crack running through the material (fracture toughness).
• absorbs more energy as crack runs through it.
• will have both ductility and strength

<table>
<thead>
<tr>
<th>Type</th>
<th>Material</th>
<th>$K_{lc}$ (MPa $\cdot$ m$^{1/2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td>Aluminum alloy (7075)</td>
<td></td>
</tr>
<tr>
<td>Metals</td>
<td>Steel alloy (4340)</td>
<td>50</td>
</tr>
<tr>
<td>Metals</td>
<td>Titanium alloy</td>
<td>44–66</td>
</tr>
<tr>
<td>Metals</td>
<td>Aluminum</td>
<td>14–28</td>
</tr>
<tr>
<td>Metals</td>
<td>Aluminium oxide</td>
<td>3–5</td>
</tr>
<tr>
<td>Ceramic</td>
<td>Silicon carbide</td>
<td>3–5</td>
</tr>
<tr>
<td>Ceramic</td>
<td>Soda-lime glass</td>
<td>0.7–0.8</td>
</tr>
<tr>
<td>Polymer</td>
<td>Concrete</td>
<td>0.2–1.4</td>
</tr>
<tr>
<td>Polymer</td>
<td>Polymethyl methacrylate</td>
<td>0.7–1.6</td>
</tr>
<tr>
<td>Composite</td>
<td>Polystyrene</td>
<td>0.7–1.1</td>
</tr>
<tr>
<td>Composite</td>
<td>Mullite-fibre composite</td>
<td>1.8–3.3</td>
</tr>
<tr>
<td>Composite</td>
<td>Silica aerogels</td>
<td>0.0008–0.0048</td>
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**Toughness** is proportional to the area under the full stress/strain diagram. From the diagrams at right, medium-carbon steel is the toughest – both strong & ductile.

Actually, the work (energy) to break the test piece is the area under the Force vs Displacement graph, since $W = Fx$. The graphs look the same, just different axis scales.
Resilience

Elastic energy. (Joules)

Toughness is the energy under the Force/Extension graph.

Resilience is the area up to the yield point, where the material is elastic.

Structural steel (ductile) has higher toughness but less resilience than high carbon spring steel.

The modulus of resilience is the strain energy per unit volume required to stress the material from zero stress to the yield stress.
**Toughness/Strength**

For the engineering materials, increasing the strength tends to **DECREASE** toughness.

The ultimate engineering material has both strength and toughness.

This is why composites appear in the high performance areas: Tough, Strong and Light.

[Diagram showing the relationship between toughness and strength for different materials]

http://www-materials.eng.cam.ac.uk
4. Creep

Under normal conditions, engineering design is based on yield stress (or UTS). However, at elevated temperatures the material may fail by stretching at a much lower stress, over a long time. The process of slow but progressively increasing strain is called creep.

The temperature at which creep becomes important will vary with the material. Lead will creep at room temperature, aluminium above 150°C, and steel above 350°C.

JET TURBINE BLADE
S. Tin, Rolls-Royce UTC
http://www.msm.cam.ac.uk/UTC/
Creep test

Creep happens slowly, and at an elevated temperature (for most engineering materials).

Here, a tensile test specimen is subject to a constant load (stress) and kept at a set temperature. The test simply plots strain over time for that particular combination of stress & temperature. Changing either stress or temperature will give a different curve. So creep is predominantly a strain issue.
Creep test

The purpose of the creep test is to record strain for a period of over time - at a certain stress and temperature. This data can be used to make predictions for the material in service.

A typical creep test has 3 stages:
1. Primary (transient)
2. Secondary (linear)
3. Tertiary (to rupture)

For a part subject to creep, the strain is monitored during the linear stage (secondary creep), and taken out of service when approaching the final stage (tertiary).
The rate of creep increases as **temperature** increases.
The rate of creep increases as **stress** increases.

**Creep variation**

Variation of Creep with Stress and Temperature:  
*Higgins Fig 3:15*
Creep temperatures

Creep becomes noticeable at approximately 30% of the melting point (Kelvin) for metals and 40–50% of melting point for ceramics. Virtually any material will creep near its melting temperature. Plastics and low-melting-point metals, (like solder) will creep at room temperature. This is obvious in old lead hot-water pipes, plastic fasteners.

CREEP IN LEAD PLUMBING PIPES: http://engineering.dartmouth.edu/defmech/Chapter_19.htm

PLASTIC FASTENERS TEND TO COME LOOSE www.directindustry.com
Creep examples: Polymers

Flat spot on a polyurethane tyre of a swivel castor. Caused by being stationary under load for a long time.

Steel bolts tightened on a plastic clamp become loose over time. The best solution is to add chopped glass fibre – especially important if temperature is elevated, such as in engine bay.

PVC hose was rolled up for a long time. Maintains its circular shape when unrolled.
Creep of Concrete

Parrotts Ferry spans 195m, the main span is one of the longest prestressed concrete beam bridges ever built in the United States.
Creep of Concrete

The central span had sagged nearly a foot during the first 5 months after opening, then almost another foot in the 10 years that followed.
Wood Creep in a roof structure: www.theroofproofers.co.za

Familiar sagging bookshelves. Particle board creeps a lot more than natural wood.

Musical instruments need to be tuned because of creep. (Well, moisture too) www.pbguitars.co.uk

**Creep examples: Wood**

Wood is prone to creep, but the mechanism is not exactly the same as metal creep. Wood is sensitive to moisture which increases creep.

An archery bow is re-strung after being stored with the string released. This prevents creep of the bow and loss of tension. www.hunter-ed.com
5. Fatigue

Fatigue is gradual crack growth caused by alternating loads.

The crack propagates from an initiating point such as a sharp corner, indent, flaw or other stress raiser.
Fatigue example

A fractured input shaft used in NASCAR racing was fractured due to fatigue progression from an intergranular stress crack, initiated at a dot peen identification marking on the shaft. (Rockwell HRC54).

In other words… The racing car got stopped by a dot on the letter “0”!
Two events of fatigue progression were observed covering approximately 33% of the fracture surface, prior to final torsional overload failure of the component.

Intergranular cracking at the initiation site indicates a brittle surface condition and may be an indicator of excessive residual stress in the surface of the shaft.
From Higgins 3.6

(i) The principle of a simple fatigue-testing machine

(ii) A typical S/N curve obtained from a series of tests

(iii) The appearance of the fractured surface of a shaft which has failed due to fatigue.

Higgins: Figure 3.16
Fatigue Testing: Wohler machine

Specimens are subjected to bending as they revolve, alternating full tension and compression each revolution.

Starting with a high load with few revolutions, the load is reduced with each subsequent test until a specimen survives ten million reversals without breaking. This stress is referred to as the fatigue limit.

The Fatigue Limit is the maximum stress that a material can endure for an infinite number of cycles without breaking. It is also referred to as the Endurance Limit.

http://www.finegrouptest.com

Ten million cycles is considered a good enough approximation for infinite.
Fatigue Testing: Wohler machine

Steelways chart dated 1955
pmpaspeakingofprecision.com
Cyclic Loading schemes

The worst-case cyclic application of stress is completely reversed. Reducing the tension helps to counteract the crack-opening. Shot peening puts the surface into compression which improves fatigue resistance.

What cyclic loading would be applied to the surface of a ball in a ball bearing?
An S-N curve (Stress vs No-of-Cycles) for Aluminium. UTS = 320MPa

Many tests must be conducted in order to plot this (average) curve. Log axis!
Endurance Limit

Some materials have a fatigue limit (or endurance limit) below which the stress can be cycled infinitely. This happens with steel and titanium under the right conditions. (Curve A)

Many non-ferrous metals and alloys, such as aluminum, magnesium, and copper alloys, do not exhibit well-defined endurance limits. The S-N curve, like Curve B will last for a certain number of cycles for a certain stress, but not “infinite”.

An effective endurance limit for these materials is sometimes defined as the stress that causes failure at 10 or 50 million cycles.
Fatigue Strength, Endurance Limit approximations.

The fatigue (endurance) limit is approximately half of the tensile strength. 
Se = 0.5 x UTS

After 1000 cycles the Fatigue Strength (Sf) is approximately 90% of UTS.

The fatigue strength to last for N cycles can be estimated by;

FS = 1.62 x UTS x (N) ^{-0.085}

where N = No of Cycles

Endurance Limit

The endurance limit is measured on polished specimens but can be reduced by:

- Poor Surface Finish
- High Temperature
- Stress Concentrations
- Notch Sensitivity of the material
- Larger Size
- Environmental corrosion, fretting
- Scratches, flaws
Stress Concentrations (Stress raisers)

Stress concentrations increase the nominal (calculated) stress due to abrupt changes, sharp corners, holes etc.

A hole in a plate causes the lines of force to be closer together. More force in same area gives higher stress.

This higher stress is called a stress concentration. The concentration factor $K$ multiples the nominal (calculated) stress.

Experiments show that $K$ increases as the hole diameter increases compared to the plate.
Stress Concentrations

Stress concentration factors for a stepped shaft under torsion.
- Three different step ratios
- A range of fillet radii.

Example:
20mm shaft stepped down to 10mm with 2mm fillet. $\sigma_a = 500$MPa.

D/d = 20/10 = 2
r/d = 2/20 = 0.1
Kt = 1.43

Allowable stress is 500MPa,
So Torque $T = 500 \pi d^3/16$
= 98175 Nmm
= 98.2 Nm
Stress Concentrations

Stress concentrations reduce the fatigue strength by a factor $K$, determined by the geometry of the notch.

The unnotched bar is in blue, where $K_t=1$. The notch has a $K_t$ factor of 3.1 (from fatigue design tables), so fatigue strength is to be divided by 3.1. In actuality, experiments gave a $K_f$ factor closer to 2.2, which indicates this material has a lower notch sensitivity factor than normal.

https://www.efatigue.com/constantamplitude/background/stresslife.html
Crack Propagation

A crack is a very effective stress raiser (stress concentration). The sharp end of the crack is like a fillet of radius ZERO!

There are calculations for this, (stress intensity factors) and predictions (but for now, let’s just say the zero radius crack can be improved by increasing the radius by drilling a hole at the tip of the crack.)

Unsuccessful stop drills – the one on the left was drilled before the end of the crack – which can be hard to find. 
http://www.mechanicsupport.com/metal_fatigue_crack.html

Successful stop drill in aircraft application
http://www.mechanicsupport.com/metal_fatigue_crack.html
The Southern Star Observation Wheel was temporarily closed in January 2009. As a result of extensive design and technical reviews a conclusion was reached to **build a new wheel**.  


**Designed in Japan, the wheel has suffered “low cycle fatigue”.**

Jay Sanjayan, an associate professor in civil engineering at Monash University,  
Read more:  
Hole drilled at end of crack

Hole drilled at end of crack

Image source unknown

EMMAT101A Engineering Materials and Processes
Designing for Fatigue Resistance

- Fatigue data varies, even in controlled environments, and especially for high cycles.
- The greater the applied stress range, the shorter the life.
- Damage is cumulative. Materials do not recover when rested.
- Fatigue life is influenced by temperature, surface finish, microstructure, presence of oxidizing or inert chemicals, residual stresses, contact (fretting)…
- Some materials (e.g., some steel and titanium alloys) exhibit a theoretical fatigue limit below which continued loading does not lead to structural failure.

Bolts designed to resist fatigue. Large fillet radii, good surface finish, threaded section larger, head minimised, surface treatment, hardened.
Surface Treatments to counter Fatigue

Shot Peening is like sand blasting but with balls instead of sand.

A ball peen hammer makes dents in a metal if hit with the ball end.

Shot types available are cast steel (S), conditioned cut wire (CW), glass bead, and ceramic. Most shot peening of ferrous materials is accomplished with cast steel shot.
Shot Peening Explanation

Metal fatigue cracks can only start where the metal is in TENSION. Never where the metal is in COMPRESSION.
Peening to Counter Fatigue

As balls (diam 0.1 to 1mm) are shot at the metal, plastically deforming the surface to a depth of about 0.5 to 3mm, depending on the part.

The dents cause the surface to try to expand sideways, but the substrate contracts back, putting the surface into compression.

This reduces the tensile component of the stress cycles, improving fatigue by up to 25%.

http://www.raw4x4europe.com/images_2/shot-peening.jpg
Peening to Counter Fatigue

A peened shaft under completely reversed stress. Tensile stress is reduced, improving fatigue up to 25%.

However, too much peening can cause excessive work hardening and residual stresses that can promote crack initiation.

Peened lettering on high strength shaft initiates crack

Tim Lovett
Show samples of aircraft parts.
Fatigue resistant features
Other Mechanical Tests

3.7.1 The Erichsen cupping test
Ductility and suitability for deep drawing processes is tested by pressing a hardened steel ball into sheet metal. The maximum depth of penetration before rupture is the Erichsen value (in mm).

3.7.2 Bend tests
Another test for ductility, but specific to bending or plastic “fatigue”. Sheet metal materials are tested for bending 180° on itself (without cracking or “orange peel” where grain become visible). Another test bends 90° back and forth until it fails – counting the number of cycles. This is definitely plastic deformation, so not really fatigue in the engineering sense.
Other Mechanical Tests

3.7.3 Compression tests

Ductile materials simply squash (barrel). Brittle materials often fracture at 45° (due to shear stress being much lower than compressive stress). Compression is the standard test for concrete.

3.7.4 Torsion tests

Torsion tests the shear stress and is a more convenient way to measure $G$, modulus of rigidity (or shear modulus $G$), which is approx 40% $E$. 
Concrete Test

High Strength Concrete

Concrete is not usually this strong, so it doesn’t usually explode like this…

The numbers: (Imperial/US units)
15.9 ksi or 200,000 lbs on a 4" diam cylinder.

Convert this to metric = 110Mpa

Concrete is usually about 20MPa, structural about 40MPa, and higher strength usually prefabricated since the W/C ratio must be very low (dry).
Online Properties Resources.

MatWeb
Searchable listing of material properties.

Graphical comparison of materials properties.

Testlopedia: Testing of plastics

Wikipedia: Materials properties

Gear Manufacturing: Shot peening

Surface treatment. Shot peening

Fatigue theory
GLOSSARY

Stress/Strain curve
Extensometer
Rockwell
Vickers
Brinell
Fatigue
Fatigue Strength
Endurance Limit
S-N curve
Peening
Stress concentration
Concentration factor
Creep
Gauge length
Yield stress
Proof stress
Young's Modulus
1. Steel wire of 2mm diameter can withstand 250MPa. What is the force?
2. Sketch a load extension diagram for low carbon steel and show the following points: (a) Elastic limit (b) Yield point (c) Ultimate tensile strength
3. A certain carbon steel has hardness of 42HRC. When hardened it is 62 HRC. Which specimen would have the greater (a) wear resistance (b) toughness (c) strength?
4. Describe the Charpy test.
5. Name three types of hardness test.
6. Describe the Rockwell hardness testing machine, and how a test is done.
7. Describe the process of a typical fatigue failure
8. List ways to improve a component’s resistance to fatigue.
10. Explain creep with reference to creep curve and jet engine turbine blades.