ANSWERS TO QUESTIONS AND 'TRY IT YOURSELF' TASKS

(NOTE: THERE ARE NO QUESTIONS FOR THE AERO-ENGINE MINI-STUDY)

BAGS

Questions

1. Some factors to consider in choosing a fabric joining process: joint strength (i.e. is the surrounding material degraded?), flexibility of joint compared to starting material, does joint need to be watertight, is joining to be manual or automated, and what are the joining costs.

2. There are many possibilities, here are some examples:

    - For a **fleece** maybe thermal insulation (could be measured by wrapping a hot water bottle in a number of layers of material and measuring the temperature as a function of time), wind penetration is also important and can be measured by stretching a piece of material over the end of a tube through which air is forced (perhaps by putting a balloon on the other end and timing the rate at which the balloon deflates).

    - For a **car seat belt**, strength is clearly important and could be measured by a simple tension test, also rip resistance is important in case it gets damaged. This can be assessed by cutting slits in strips of materials, gripping one side and hanging weights on the other side until it rips.

    - For a **dish cloth**, water absorbency is important, this could be measured by weighing materials, submersing them in water and then withdrawing and weighing them again to assess water uptake; wet strength may also be important.

    - For a **wet suit**, water penetration is important and could be assessed by stretching material over a beaker and turning it upside down and timing the rate of water loss, flexibility/elasticity is also important and could be assessed by a tensile test to measure *elastic* deformation before failure. The effect of pinholes on strength could be investigated.

3. Polymers are made of long-chain molecules of carbon atoms, with other light atoms (like hydrogen and chlorine) attached on the side. Carbon-carbon bonds are very stiff and strong (as demonstrated by diamond). In bulk polymers the chain molecules are crumpled up and are easy to stretch (just by straightening them out), whereas in fibres they are already quite straight so loading the fibre stretches the stiff, strong carbon-carbon bonds.

Try it yourself

1. Alternative processes for joining fabrics:

   a) **dielectric (radio frequency) welding**: uses microwaves to heat the joint under pressure (e.g. PVC ring binders, document wallets)

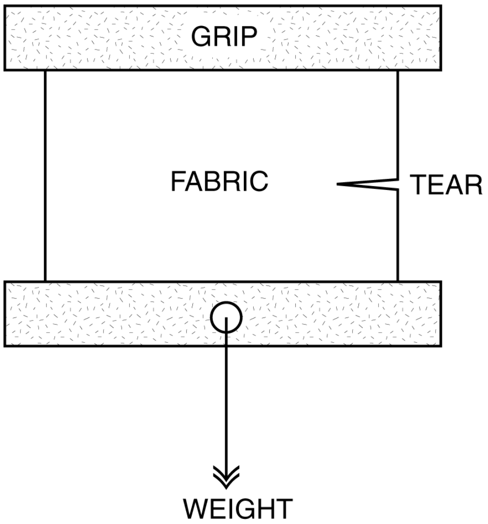
   b) **hot plate/hot wedge/hot bar welding**: uses an electrically heated plate/wedge/bar inserted in the joint to soften the material; this is withdrawn and the joint forged together (e.g. polythene gas pipes)

   c) **adhesives**: conventional joining method for sheet materials, often used in addition to or instead of stitching where watertight/airtight joints are essential (e.g. inner tubes, rubber boats, wetsuits, tents)

2. Stitching (rucksacks), rivets (sports bags, handbags), hinged moulded handles (suitcases).

   Joints introduce "stress concentrations", and are also the most heavily loaded part of the product (also frequently subject to accidental overloads or misuse – e.g. airport baggage handling!)

3. Tear resistance, can be measured using the test-piece shown here. The 'grips' should support the whole of each edge to make sure there is load at the tip of the tear. The bottom grip may not hang level as the tear gets longer, but this does not matter much.



4. The fibres in newsprint are clearly visible. If looked at under a microscope it will be clear that the fibres are not randomly arranged - most of the fibres are approximately parallel to one another due to the way in which the paper is made (by rolling and stretching). This makes it easier to tear the paper parallel to the predominant fibre direction than across the fibres. This is because a crack can run more easily along the line of the fibres than when it has to cross many fibres.

MATERIALS IN THE KITCHEN

Questions

1. Tupperware's excellent seal depends on the recoverable elastic distortion it can undergo which enable air-tight mechanically interlocking seals to be made between lids and container bodies. Cling film works by a quite different principle. For tamper-evident packaging shrink-fit heat seals are often used.
2. Knobs and handles on saucepans are often riveted, spot welded or screwed on. Polymer handles are often moulded directly in place (e.g. onto a metal spatula on knife blade). Joining ceramics is especially difficult (the handles often fall off mugs and cups).

Try it Yourself

1. An oven with reasonable low temperature control is required. Place a foil tray in the bottom in case the temperature gets too hot! One experiment is to monitor the change in shape of a polystyrene cup as the temperature is raised. The other is to measure the deflection of different polymer rods or strips under their own weight as the temperature is raised.

2. A test here might involve submersion of paper plates (or strips of plates) in water/ketchup/etc for different (short) times followed by a simple measurement of a strength/stiffness.
3. Most polymer containers have been made by injection moulding. In this case a 'pip' where the polymer is inlet is clearly seen, or a 'parting line' where the parts of a mould have met. In transparent and semi-transparent polymers interference patterns can be seen when the article is viewed between crossed polars indicating molecular alignment frozen in during manufacturing.

WALKING AIDS

Questions

1. Walking sticks and Zimmer frames usually have a rubber sleeve over the bottom, which gives good friction on all normal floor and outdoor surfaces (including polished wood or tiles). Leisure walking sticks can also have rubber on the base, but for rougher terrain (including snow) moulded tips are used giving both a spike and a small snow "basket" (like a skiing pole) – the spike gives a good location in soft ground, while the basket stops the pole sinking in too far. The most expensive mountaineering poles use hard tips (tungsten carbide) to protect against rapid wear on rocks.

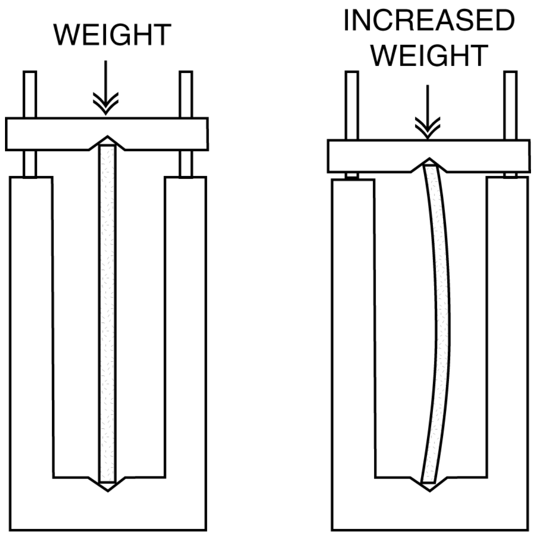
2. Aluminium can be "anodised" – controlled surface chemical reactions **-** (which also improves resistance to corrosion) with attractive silver, purple or gold colours.

3. Benefits of telescopic tubular design is that the length can be adjusted to fit the user as they wish, and the stick packs away to a much shorter length for easy carriage on a rucksack or in the car. Various devices are used which involve a twist to unlock, slide to the required length, and twist back to lock – an example is a threaded nut which pushes a tapered sleeve into the gap between the two sections of the pole. Anti-shock features include springs mounted near the tip (which can sometimes be adjusted to change the amount of "give"). A benefit to the user is reduced risk of strain to the arm by softening the impact on the hand and wrist.

4. This is most likely due to the high cost of traditional labour intensive methods being uncompetitive with cheap imports. No manufacturing firm can expect to stand still and this highlights the need to be continually assessing new technologies, materials and manufacturing methods. Morgan cars is one of the few examples where high labour input is unimportant as the prestige of the product justifies the high costs. The walking stick manufacturer could have tried this approach by aggressive marketing towards the higher margin markets (e.g. leisure walkers) and emphasising quality over cost. In addition, however, investment in innovation and technology to produce new products (such as collapsible mono-pods) would have been useful to maintain a diverse product range that would be less susceptible to mass produced imports. The firm could also have considered partnering with the foreign company to combine the good name of the British firm with the cheap production capability of the foreign manufacturer.

Try it yourself

1. A means of calculating the buckling load is the load at which the rod buckles in the rig shown here. For an unclamped circular rod the buckling load F should vary with the Young's modulus (at constant length and area); for a given material, it should vary with the square of the cross sectional-area (or the 4th power of the diameter) and inversely with the square of the length. For a solid circular rod, this can be summed up as F = constant * E * d^4 / L^2. Note that cross-section shape is very important too (e.g. tubes vs. solid rods), but this is more difficult to investigate and quantify.



Rig for buckling test

2. A collapsible Zimmer could be based on designs involving hinged joints, telescopic components or bayonet fixtures, or even elastically bi-stable structures such as employed in the straight/coiled behaviour of tape measures. Current Zimmers have spring-loaded “buttons” allowing the length to be changed in fixed intervals. Leisure walking poles are telescopic, with a twist fitting to clamp the inner pole at any position – this could be adapted for tripod Zimmers, but the fixed settings for leg length on a frame Zimmer ensure that they do not wobble (i.e. all 4 feet on the ground).

HELMETS

Questions

1. Cycle helmets are often extensively styled and coloured; hard hats are yellow for good visibility on building sites; horse riding helmets are usually black velveteen and are part of the horse rider’s uniform; climbing helmets are larger than cycling helmets and carry brand names and logos; army helmets are camouflaged to reduce visibility and are metallic for good strength, toughness and wear resistance.

Try it yourself

1. The standard test involves using standard rectangular or circular specimens (usually notched) and snapping them using a heavy pendulum. The lower height reached on the follow-through provides a measure of the impact energy absorbed. Another test involves dropping a weight (e.g. a horizontal cylinder) onto a simply-supported beam of the test material (un-notched, or notched underneath on the tensile edge) – by systematically increasing the drop height, a measure of the impact energy is obtained. A problem with this test is that earlier impacts which do not break the specimen may nonetheless do some damage, so the final drop height for fracture is reduced.

WORKSHOP TOOLS

Questions

1. Cast iron is used for vices etc. because it is cheap, and easy to manufacture into difficult shapes (like a vice body). Being easy to machine, precise flat surfaces can be made (e.g. for V-blocks) and being hard they resist scratching, denting or wear (retaining their dimensional precision).

2. Spanners require good toughness and high strength. A worked (forged) structure is therefore best, as the microstructure is more uniform and fine-scale in a forging, compared to a casting. The deformation in forging will also directly increase the strength, by "work hardening". There could be a market for cast spanners in less demanding environments (e.g. home use) if they were significantly cheaper – but this is not the case in practice (at least for spanners because of their simple shape, the same is not true for all tools). Disposable spanners (such as sometimes found in flat-pack kits) are often made from stamped steel sheet, with a pressed-in ridge to provide stiffening.

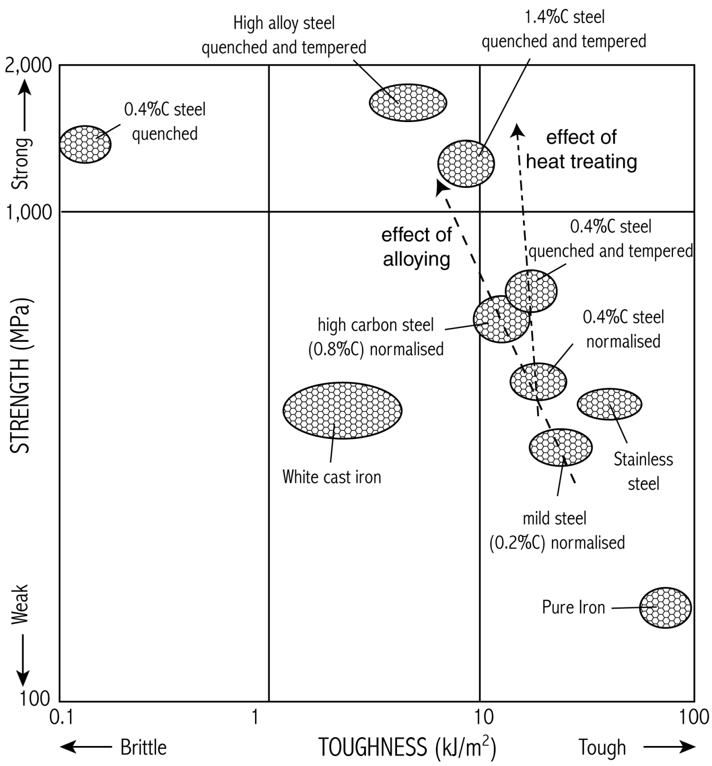
Try it yourself

1. The easiest method is perhaps the scratch test in which a hard material is scratched over the surface of the material and the depth of wear grooves measured or the weight loss due to erosion measured. This is usually achieved by a pin-on-disc experiment in which a disk is rotated at speed with a pin pressed against it under a given load. The test material can either be the pin or the disk.

Hacksaw blades

- Increasing carbon content *increases* the strength but *decreases* the toughness.
- Quench and tempering normalised steel *increases* the strength, but not does not significantly reduce toughness.

A good estimate of the strength and toughness of Q&T 1.4%C steel is therefore as shown opposite.



ROPES

Questions

Data:

	Young's Modulus	Strength	Density	Elastic Strain at failure	Stored Energy per unit volume at Failure	Stored Energy per unit mass at Failure	Specific Stiffness	Specific Strength
Units	(GPa)	(MPa)	(kg/m3)	(%)	(MJ/m^3)	(kJ/kg)	(MNm/ kg)	(MNm/ kg)
Cotton	7.9	225	1,540	2.9	3.2	2.08	5.13	0.15
Hemp	32	300	1,490	0.94	1.4	0.94	21.5	0.20
Bulk Polyester	3	50	1,300	1.67	0.42	0.32	2.3	0.04
Bulk Nylon	2.5	63	1,090	2.52	0.8	0.73	2.3	0.06
Carbon Fibre	300	3,430	1,770	1.1	19.6	11.1	169	1.94
Aramid Fibre	124	3,930	1,450	3.2	62	43	85	2.71
Polyester Fibre	13	784	1,390	6	23.6	17	9.35	0.56
Nylon Fibre	3.9	616	1,140	15.8	48.7	42.7	3.42	0.54
Alloy Steel Wire	210	1,330	7,800	0.6	4.21	0.54	26.9	0.17
Spider Web Silk	11	1,000	1,310	9.4	48	37	8.4	0.79

Note strength is **not** breaking strength, but a measure of elastic (yield) strength. In addition, the elastic behaviour is not always linear-elastic (i.e. like a spring), so the value for Young's modulus is only representative. As a result, the calculated value for elastic strain at failure (and stored energy) should be taken as approximate. The synthetic fibre properties are for continuous fibres (long) not staple fibres (short). Fibre properties can also be significantly affected by temperature and the rate of loading.

1. High elastic stored energy is essentially what is needed for a product which acts as a spring. Elastic stored energy per unit mass can be calculated by dividing stored energy per unit volume by the density. It is more useful than per unit volume for products which store energy but must be carried or transported (e.g. archery bows and pole vaults, or leaf springs in vehicles). Composites based on high strength fibres (like CFRP) are very attractive for competitive sports products (like vaulting poles), as they make very efficient springs. Often volume is important as well, so both volume and mass must be considered – this applies to all the examples given.

2. Spiders' web silk has very good specific strength (790 kNm/kg) which is much better than steel (see specific strength-stiffness selection chart). This is because the polymer is aligned as it is drawn through a spinneret from the rear of the spider. There are a variety of natural silk fibres, of which spider drag-line silk is only one example.

3. 120 tonnes is about 1,200kN. The cross-sectional area of the rope can be worked out from σ=F/A, where σ is the strength of the material, giving A≈0.000902m^2 = 902mm^2. The diameter of the steel cable is, therefore, roughly 34mm. Workshop lifting cranes will have more than one cable, so we really need to compare the areas. A 120 tonne crane has a total cable area of about 30,000mm^2 so the safety factor is about 30. Note:

   - this comparison is slightly misleading as we are comparing cable with a single solid strand;
   - conventional lifting equipment is unlikely to use high alloy steel wire so the material strength will be lower requiring a bigger cross-sectional area;
   - dynamic effects (e.g. when first lifting) mean that the maximum load the crane 'feels' may be higher than 120 tonnes (you can show this finding a heavy weight you can just lift slowly with a piece of cotton, and then trying to lift the same weight by 'jerking' it off the floor);
   - some of the steel strands are likely to fray, so the optimum strength may not be achieved.

4. Bungee ropes (high safety factors), tow ropes (medium), anchor cables (medium), cable car wires (high), telephone cables (medium/high), parachute cables (high), dog leads (low/medium), electric cables (high), hammocks (medium), fishing nets (medium), shoe laces (low).

Try it yourself

1. - **Rubber bands** are lightly cross-linked network polymers. Because there is a large distance between the cross-links the rubber can uncoil from its usual random coiled-up configuration to achieve great lengths, but the cross-links provide the "memory" to pull the molecules back to their coiled-up state. The greater the number of cross-links the greater the stiffness. Bands of different colours and cross-sectional areas will give a wide range of stiffness, strength and elongation to failure – partly because of the different dimensions, but also because of the range of rubber mixtures used.
   - **Car tyres** are more densely cross-linked (by "vulcanisation") to achieve greater stiffness. In sunlight more cross-links are formed making the rubber more brittle (old rubber bands often crack when pulled). Carbon black is added to tyres to prevent degradation in sunlight. Rubber is in fact always a brittle material (just put a pin-prick in a balloon to prove it!) so that a small cut will seriously reduce the strength.