CHAPTER 2

Engineering Application Module 2 – Personal and Public Transport

Historical and Societal Influences

Historical Developments in Transport Systems

Cycle development

The bicycle is an interesting machine to have developed. Prior to it, nothing existed that operated on the principle of balanced travel and it has only extended to the motorcycle. The car is merely a progression from the horse drawn cart, while the truck is a development of the old bullock teams. **The bicycle, however, marked the beginning of a new style of transport.**

Early Machines

The invention of the bicycle has been credited to a Frenchman, le Comte de Sivrac, who introduced his machine, the *célérifère*, at the Palais Royal Gardens (Jardin du Palais Royale), in Paris, in 1791. He put wheels on what had been a child's toy, the rocking horse.

The célérifère was renamed the *velocipede* or dandy-horse and efforts were made to improve the appearance by making it resemble animals such as lions, horses or even dragons. In 1816, a German, Baron Karl von Drais von Sauerbron improved the original velocipede by fitting a steerable front wheel, armrests, a padded seat and even a primitive rear wheel brake. His machine was called a *draisienne* and was still propelled by walking it along the ground. The draisienne became popular, especially in England, where it became known as the hobby-horse.

The method of human propulsion on the early machines was hardly ideal. The introduction of mechanical propulsion was sure to come. In 1821 an Englishman, Lewis Compertz, designed a rack and pinion (a cog meshing with a toothed rack) system so the arms could be used to assist the feet pushing along the ground. It was not a perfect solution but definitely an improvement.

Pedal Power

A Scottish blacksmith, Kirkpartick Macmillan, developed a pedal drive in 1839. He used a pair of hanging stirrup pedals, attached to long arms, that connected to cranks on the rear wheel. It was similar in principle to the locomotive drive, with the backwards and forwards motion of the pedals converted into rotation by the cranks on the back wheel. Gearing was determined by the size of the rear wheel; the larger the wheel, the higher the gear. Macmillan's machine, sometimes called Macmillan's Velocipede, weighed just over 30 kg. It was archaic in concept and construction but it now enabled a rider to travel without having to push with his feet on the ground.

Rear wheel drive was not to become popular on bikes for a long time. The next stage of bicycle development was front wheel drive. In 1861 Monsieur Brunel took his draisienne for repairs to a coach maker, Pierre Michaux. Michaux's son, Ernest, suggested that the machine could be improved by fitting cranks, with pedals on the ends, to the front wheel so that it could be pedalled.

By 1867, at the Paris Exhibition, this new bicycle, the velocipede (the cynics called it "boneshaker") had became, an established mode of transport. Michaux opened a factory and employed 300 workers to produce these bicycles. Soon three-wheeled, four-wheeled, tandem and even triplet versions of the velocipede appeared. Schools for riding sprang up, and organised races were introduced.

Lady cyclists on "boneshakers" were among the first women to cast skirts aside and appear in public showing stocking covered legs. "Bloomers" for cycling, based on baggy pantaloons were popularised by Mrs Amelia Bloomer in America. In 1874 Englishman James Starley, famous in the cycling world, patented the first 'lady's' bicycle. It was ridden side-saddle with one pedal. Starley also invented the spoke, radiating at an angle from the wheel hub.

The "Old Ordinary" (Penny-Farthing)

As with the car the speed of bicycles has been something that has motivated new designs. The problem with the velocipede was that it moved along only one wheel circumference per turn of the pedals, because there was no variable gearing. Before gears, the solution was to increase the front wheel diameter so that, for each rotation of the wheel, the bike went further. Wheels became larger and larger with the only limitation being the length of the rider's leg. The new bicycle had a large front wheel up to 1.52 m (5 feet) in diameter and a small rear wheel. Released in 1870, it became known as the *Old Ordinary* or *Penny Farthing* (two British coins). In retrospect the Old Ordinary was not a particularly feasible design. It was unstable and when braking heavily it usually sent the rider over the handlebars. Descending hills was a thrilling, if not dangerous, experience as the pedals span wildly. To counter this final problem, footrests were fitted high on the front forks so that the rider could free his/her feet from the pedals. Although they were tricky to ride, they were the fastest things on two wheels until the chain driven 'safety' bicycle appeared.

Fig. 2.1: *The Kangaroo bicycle mixed the design of a Penny Farthing with an early chain drive in an attempt to reduce the front wheel size. (http://en.wikipedia.org/wiki/File:Kangaroo_Bicycle_Rev.jpg)*

The Safety Bicycle

Attempts to make the front wheel smaller, and therefore the bicycle safer, were defeated by the lack of a feasible solution at the time. A reliable bicycle chain was a major invention needed to develop a safe successor to the Old Ordinary. James Starley gave us the makings of the modern bicycle when he developed the Rover 'safety' bicycle of 1885. Starley had already designed a chain-driven bike for Rover in 1880. It had linkage steering of the front wheel, which was still larger than the rear wheel. His new design brought together some of the main elements of the modern machine: geared chain drive, wheels of equal size, direct steering, inclined forks, and the diamond-shaped frame. These safety bicycles were a vast improvement on the Old Ordinary. Not only were they easier to mount and ride, they allowed improved gear ratios, which made them faster but requiring less effort to ride.

Fig 2.2: *An 1886 Rover Safety bicycle (left). A Dursley Pederson bike from 1898 is shown right. The Pederson bicycle used multiple small tubes to create a truss both longitudinally and laterally. Note the hammock style saddle.*

Initially there was some resistance to the new design but another development was about to make the "Rover Safety" the number one design. In 1888 a Belfast veterinary surgeon, John Boyd Dunlop invented the pneumatic cycle tyre. Prior to this, all tyres were solid rubber. With pneumatic tyres the bicycle was more comfortable so the rider could travel even faster. Sensing the commercial value of this, Dunlop went into the tyre manufacturing business, and within a few years, the pneumatic tyre had completely replaced the solid tyre as standard equipment on bicycles and on the new inventions, cars and trucks. The Dunlop Company had become the largest in the tyre business.

Mass Production

By the late 1800s the bicycle had ceased to be a novel status symbol and was becoming a cheap and practical form of personal transport. Mass production of the bicycle began, and by 1914 the practical utility bicycle was being assembled from some 300 separate components. The majority of these were manufactured by specialist firms. Many cycle companies were the core of the fledgling automotive industry, for example Morris and Riley and Peugeot.

Up to the Present

Through the 1900s bicycle frame design did not change a great deal. The frame angles were altered and different alloys were used to reduce weight. By the 1960's, high strength, lightweight aluminium alloy frames were used and new gearing systems were developed. Nowadays we see very base end bicycles made from mild steel tubing, entry level road and mountain bicycles using aluminium alloys and high end bicycles now use carbon fibre reinforced polymers.

Big developments occurred in the 20th century with gearing and braking. By the 1990's the mountain bicycle had demanded wider range gearing and the simple 10 speed derailleur system expanded out to take in first 7 speed rear clusters with now 10 speed rear clusters being the norm for high end bicycles. Front derailleurs have remained two speed for most road bicycles and 3 speed for mountain and touring bicycles. Hub gears are rare in Australia but are used extensively on city and folding bicycles through Europe. Derailleur gear systems are more efficient than hub gears but require more maintenance. Currently the "fixie" is very fashionable, using only single speed chain drive, in a modern road bike frame.

Photo to Come

Fig. 2.3: *The rear derailleur from a modern road bike, here the derailleur moves the chain left to right across 10 different cogs ranging in size from 12 teeth to 25.*

Brakes have improved with cast aluminium alloys now allowing dual pivot calliper brakes with good braking performance and also lightweight for weight conscious road bicycles. Early mountain bicycles used cantilever brakes, which were predominately replaced by V brakes and now disc brakes; both cable and hydraulic discs are used on mountain bicycles.

Modern Bicycles

Mountain Bikes

Initially the term "mountain bike" was marketing exercise; simply a standard diamond frame bike that had been more heavily constructed to stand up to off road riding. Mountain bikes typically have smaller wheels than road bicycles (ETRTO 559 mm) with knobbly tyres. Such tyres are not ideal for road riding because of the high rolling resistance. However entry-level mountain bicycles have become the bicycle of choice for recreational cyclists. These typically use aluminium alloy frames (such as 7000 series). High-end mountain bicycles are popular with off road riding and various competitive events exist for such cycling. Here carbon fibre reinforced frames dominate.

Fig. 2.4: *A dual suspension mountain bicycle left and a road bicycle on the right. Both have carbon fibre reinforced polymer frames.*

Most high-end mountain bicycles use dual suspension designed to cope with the rough terrain.

Road Bicycles

The modern road bicycle typically uses an aluminium alloy frame for entry-level bikes and then carbon fibre reinforced polymers moulded frames are used with more expensive models. They have large diameter (ETRTO 622 mm) but narrow wheels and tyres. Road bicycles rely on some flex in the frame to provide improved pedalling response and some release from road vibrations, but require rigidity as well so pedalling forces are not lost. Originally steel and alloy steel frames offered this perfect compromise, but desire for lighter weights led to aluminium alloys which tend to have less flex because aluminium alloys have no definite fatigue limit so frames are built with little or no flex. Carbon fibre reinforced polymers offer the ride of steel but are lighter than aluminium alloys so they are now the frame material of choice. Although their durability in terms of long term ownership is questionable.

Moulton Bicycles

Fig 2.5: *The Moulton NS Double Pylon, 304 stainless steel tubing silver soldered with almost 200 individual soldered joints. It has with rubber suspension front and rear.*

Alex Moulton's bicycles pioneered the use of small wheels with high-pressure tyres. Prior to this small wheel bicycles were simply children's bikes. Moulton proved that small wheels with high-pressure tyres were the equals of large wheeled bicycles.

However they had a rougher ride so he fitted suspension as well. Moulton bicycles were very popular in the 1960s but as the craze waned Moulton moved into high quality small volume bicycle production and his designs now use a complex stainless steel space frame design, which is light, strong but quite expensive.

Folding Bicycles

There are a wide variety of bicycles that took the small wheel concept pioneered by Alex Moulton and developed them into bikes that can fold for easy commuting and transport. One of the best examples of a folding bicycle is the Brompton bicycle. Within 20 seconds a Brompton can be folded to a package less than a quarter its original size. Although the Brompton is clearly designed with city riders and commuters in mind, its devotees have toured all over the world on them.

Fig 2.6: *Brompton folding bicycle, unfolded and folded.*

Recumbent Cycles – Or Riding Reclined

The concept of the recumbent bicycle (and tricycle) is a sound engineering principle. The human body is not really designed for the arms to support a person's weight. Yet the common or upright bicycle requires that part of the body weight is supported by the arms. The bicycle saddle, developed many years ago, is not designed to support all of the rider's weight. If one sits vertically, without putting weight on the arms, the bottom will soon get sore.

Recumbent bicycles

Fig. 2.7: *An M5 Shockproof cro-moly steel frame recumbent bicycle with dual suspension and a CFRP frame M5 high racer recumbent (photo courtesy http://flyingfurniture.com.au/)*

The recumbent bicycle is one solution. The larger, more comfortable seat, has a backrest and is reclined like a car seat. The pedals are out in front. The rider's arms carry no weight. A softer, larger seat makes for greater comfort and lower frontal area because it is reclined. The machine is more aerodynamic and finally, if the rider falls off, he/she has less distance to fall. Conversely they are heavier, more costly, and harder to balance, especially initially.

The world of recumbent bicycles is highly diverse and covers many different styles, materials and manufacturing methods.

Recumbent Tricycles

Fig. 2.8: *Greenspeed GLR road racing trike (picture courtesy Greenspeed, www.greenspeed.com.au)*

The upright tricycle is primarily a child's toy or a load carrier. With the high centre of gravity they have a tendency to roll over. One of the disadvantages of a bicycle is the need to balance it and the rider must allow the bike to wander slightly from side to side in order to maintain balance. The tricycle is a solution to this, but, it is highly susceptible to rolling at moderate speeds. The recumbent tricycle has a low centre of gravity so rolling is far less of a concern, and there is no balance issue.

Because of their extra mass, tricycles tend to be a slower on hills but on the flats and downhill they are equally as quick as any bicycle. They can also corner as quickly as any bicycle. Being low, means that they have an aerodynamic advantage in head and cross winds. They are better in wet conditions than the bike because their design makes them more stable when cornering. But they are heavier and more costly than an equal quality upright bicycle.

Car Development

Introduction

In Chapter 2 of Volume 1 we looked at the development of the motor car by looking at some key designs. Books and books have been written about the development of the car. The author suggests that when considering car design and the impact of the engineer, it is appropriate to consider key designs such as the Ford Model T, the Volkswagen Beetle, the Citroën DS and the BMC Mini. Naturally other cars have advanced car design, but these cars significantly changed car design, or they were big sellers that effected society in some way.

Car Propulsion.

It is nearly 12 years ago since the author wrote the first edition of this book and at the time hybrid technology seemed to be on the march. Yet twelve years on hybrid cars have barely made an impact, with Toyota/Lexus and Honda being the prime drivers with other companies proposing but yet to release hybrid vehicles. Instead we have seen the petrol engines improved with direct injection designs, and we have seen diesel engines given advanced engine management and injection systems that have vastly improved their performance while maintain their economy. All this has meant that hybrids have gained little traction in the market, and the long proposed fuel cell cars seem even further away.

Train Development

So far, all of our forms of transport have been personal transport. We shall now turn our attention to a public transport system. In the following section some important developments in trains will be discussed.

From the 14th to the 18th centuries the train was in use but horses powered it. Many wagons were hauled up out of mines using "pit ponies", and this practice continued in Australia until the 1950s. Originally rails were timber but iron rails were introduced in 1728 in England. In 1803 the first public railway was opened for hauling freight; it was just over 15km long and ran from Wandsworth to Croydon in Southern England. This was followed in 1806 by the first public passenger line with a horse-drawn train in South Wales. In Australia the very first railway was in Tasmania and was actually convict powered. The train ran on rails, but instead of a steam engine, the convicts ran alongside the train, pushing it.

Steam Trains

In 1803 the very first steam locomotive was constructed by Richard Trevithick for the Coalbrookdale Ironworks. He built a second locomotive the following year and it was apparent that this machine could do more work than a horse at a speed of 8 km/h. Trevithick used his high-pressure steam engine as opposed to competing atmospheric steam engines that were used for driving pumps and machinery. This heavy locomotive, however, broke up the rail line, so it was abandoned.

In 1812 the first locomotives to conduct regular work were designed by John Blenkinsop, for a colliery in Yorkshire. They differed from current trains as the wheels and tracks had interlocking teeth. Blenkinsop felt that smooth rails would slip too easily. Trevithick had proved this was not the case, but Blenkinsops's system was to reappear, in a modified form, for mountain railroads.

George Stephenson, a mine mechanic, invented a locomotive in 1814, and it was to be the first step in his work of developing railways. Stephenson was a railway man through and through. He envisaged a railway system criss-crossing the country, carrying freight and passengers alike. In 1823 he was appointed as the engineer to the Stockton and Darlington railway. This 16 km line ran from a colliery to the port of Stockton-on-Tees, and was opened in 1825. His locomotive, *Locomotion,* was designed with his son, Robert. It was the first locomotive to haul on a public line and was capable of speeds up to 25 km/h.

Stephensons' *Rocket* is a famous locomotive and it had an immense impact on locomotive design. The future of profitable railways rested in providing quick passenger transport; something that was previously unavailable. In 1829 a series of trials were held to determine the best locomotive design. George and Robert Stephenson entered their *Rocket*, which had an innovative boiler design; 25 tubes carrying water ran through the firebox, more efficiently creating steam. Along with an improved exhaust system, The *Rocket* was twice as fast as rival designs; it could pull a 14 tonne train at 46 km/h.

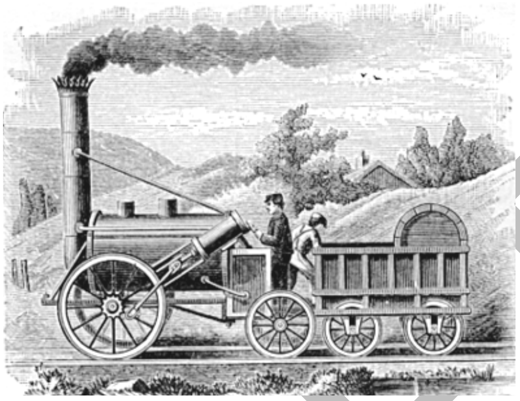


Fig 2.9: *Stevenson's Rocket of 1829*

The *Rocket* started an epoch in train design. From that moment, rail transport expanded, as it offered speedier transport than horse-drawn services. Naturally the challenge was to get trains to go faster and faster, but along with such increases in speed came difficulties in stopping the vehicles. Mechanical brakes were difficult to use, but in 1869 George Westinghouse patented an air brake design that was to become widely used. Operation centred on the brakes being *held off* by the air pressure. When the air pressure was released the brakes were applied. This made it safer if the train lost its air pressure, than if the system operated in the reverse fashion.

Another big advance in steam locomotive design was the development of the compound steam engine developed by Anatole Mallet in 1876. Instead of used steam merely being given off, it was first used in a small cylinder, then used in a larger cylinder, so the steam was used twice. Following "compounding", there was superheating, which was initially adopted in Germany in 1898. The moisture content of the steam produced by the boiler was reduced by increasing the temperatures, hence increasing the efficiency of the motor.

If one looks closely at railway design one may notice that railways neither are very steep, nor do they have very tight curves. Tight curves are difficult for trains to negotiate, while steep grades mean they lose traction. While cars can comfortably, even if a little slowly, ascend a grade of 1 in 6, trains are lucky to climb grades higher than 1 in 25. The solution to both of these problems is to produce large sweeping curves and to use tunnels and cuttings to pass over hilly terrain.

The standard steam locomotive has one or two large driving wheels, with many smaller wheels that are carried as pivoting bogies to balance the train at front and back. The train often carries a tender carriage behind it containing water and coal, which has no drive wheels under it. The problem with this is that a lot of the weight is not carried over the drive wheel, so on steep grades, the wheels will slip. Two types of locomotives that avoided this were the Garret and the Shay.

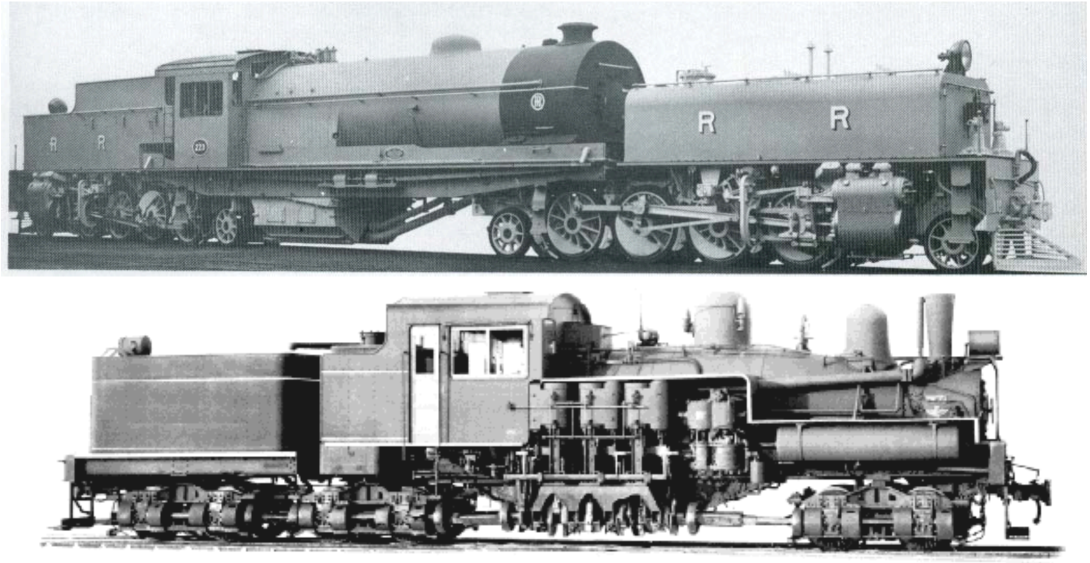


Fig. 2.10: *A Rhodesian railways Garratt locomotive (top) and the clever and specialised Shay locomotive (bottom).*

The Garratt locomotive was made in three articulated parts; the middle was the boiler and cab while the front and back carriages were the tenders for water and coal respectively. Unlike other trains, the bogies on the tenders were driven, so you there were more driving wheels and therefore less chance of wheel spin. Garratt locomotives were very large, yet could deal with tight curves. The main disadvantage was the wear on the pipes that carried steam to the tenders at either end.

The Shay locomotive was a truly fascinating design. The boiler is offset to the left side of the locomotive to allow a set of three vertical pistons on the right hand side. These pistons moved up and down and were connected to a crankshaft that ran along the right hand side of the locomotive. Mounted to the crankshaft were pinions that engaged with bevel gears on every wheel. This meant that every wheel was a driving wheel, as the left side wheels were connected to the right hand wheels by axles. The crankshaft had to have universal and sliding joints to allow the bogie to turn, and the tender also had drive wheels underneath to improve traction. The main advantage was that each wheel was driving so wheel spin was less likely, and it was designed to deal with tight curves. The disadvantage was that the design was slow, with a maximum speed of 25km/h and it suffered a lot of wear in the universal and sliding joints.

Four Shay locomotives were used in NSW, on a private railway line that ran into the Wolgan Valley to ferry refined shale oil from the refining plant. At the time of operation (1909-1911, then intermittently up to 1932), rail transport was the only option available for freight. It was also the main source of income for the residents of the township of Newnes, now a ghost town. The railway was a miraculous feat, with tight curves and 1 in 22 grades and only two tunnels. Although the line is gone it is possible to walk along the old track that was the line. One tunnel is now a home to glow-worms, a tourist attraction for the Lithgow area.

Gauges – to be wide, or not to be wide; that is the question!

Gauge refers to the distance between the tracks. By the 1830s it was a hotly contested issue. Originally the gauge of lines was 4 foot 8½ inches, or approximately 1.44m. This odd size came about, as that was the gauge of the lines that coal mines used with the wagons pulled by pit ponies. There is also some evidence that this strange size dates back to the distance between the wheels of Roman chariots. All railway engineers simply used this accepted gauge, except Isambard Kingdom Brunel. We discussed Brunel's bridge designs in Chapter 1. He was responsible for the Great Western Railway (GWR) in England. Brunel felt that a wide gauge of 6 feet (1.83m) offered distinct advantages, and he was right. The wider gauge makes a train more stable and less likely to roll, as its wheels are further apart. It does, however, make tight curves even more difficult.

Unfortunately he was the only person to adopt this gauge and as more railways sprang up around England it became clear that the wide gauge days were numbered. In Australia, the eastern states could not agree on the gauge for their railways. NSW used the standard 4'8½" (1.44 m) gauge, while Victoria used a 5'2" (1.57 m) gauge and Queensland used a narrow 3'6" (1.07 m). This ridiculous mismatch was only rectified in the 20th century, when the gauges in Victoria and Queensland were adjusted to the NSW standard.

Electric Trains

The first real challenge to the dominance of steam was the electric train. With reliable electric motors and power stations, both available by the 1880s, electric trains were a viable option to steam. One clear advantage was that they were less polluting. The power station still polluted but it was away from the rail line and was much more efficient in converting coal to the power source (electricity) than a large number of steam engines They were also quieter. The disadvantage is that they need infrastructure in place to provide power, because an electric train cannot use just any rail line.

The fist electric train design was shown by Werner von Siemens at an 1879 Berlin exhibition, and by 1883 public electric lines were opened. The electric train offered great advantages with its underground rail lines. This was an answer to congestion in cities. In 1890 the first electric underground railway was opened in London and it has since become an essential part of the city's transport. In Sydney the underground stations of Museum and St James were opened in 1926. Town Hall and Wynyard stations followed in 1931, and with the completion of Circular Quay station in 1956 the City Circle was created. In the London Underground, electric trains were essential. Electric trains have been used on suburban railway lines since the late 1920s in Sydney, while outlying areas like Wollongong, Newcastle and Lithgow did not gain electric trains until the 1980s.

Electric trains need to have power provided. In NSW, the power is provided by copper, overhead wires. Some of the trains' carriages have a pantograph that is connected to the electric motors that run along the overhead wires. In other situations, a third rail, between the other two, is used to provide power. Without these systems, the electric train cannot run, but with them they are a viable option. Many goods trains in NSW are pulled by electric locomotives. It is important to emphasise that ***electric***

trains do not stop pollution; they merely move it from the city to wherever the power station is.

Diesel Trains

The diesel train is the true successor to the steam train. Electric trains ran alongside steam trains in the cities but they could not service outlying areas. The first diesel train ran in 1912 in Germany, but the future for diesel trains lay in the diesel electric arrangement, where a diesel engine drives a large generator that uses electricity to drive electric motors at the wheels. This is a far better system than a gearbox, for large power delivery. Another system uses hydraulics to connect the motor and wheels and this is called a diesel hydraulic drive. A diesel motor drives an hydraulic pump which creates high pressure oil in pipes. The pipes feed hydraulic motors, mounted on the wheels.

By the 1960s in NSW, diesel trains were becoming widespread and by the early 1970s the steam train was gone. Diesel electric trains are extensively used for long distances. In NSW, for example, the diesel electric system is used on the XPT rail services and it is extensively used when hauling freight. Two large diesel electric locomotives haul the Indian Pacific that runs from Sydney to Perth. The Explorer and Endeavour passenger trains, in NSW, use a diesel hydraulic system.

Effects of Engineering Innovation in Transport on People's Lives

It is important to the study of historical topics that students learn how to make notes. Following is a note summary of effects of innovation on people's lives.

Cycles

- The pedal-powered velocipede, 1839, greatly improved the usability of the bicycle.
- Old Ordinary (Penny Farthing) – faster transport than the velocipede but dangerous to ride
- Rover Safety Cycle, 1885 – safer transport with similar speeds
- 1888 – Dunlop's pneumatic tyres
- Early 1900s – mass production of the bicycle
- Freewheeling hubs made cycling far safer for riders
- Internal hub gearing – improved bike as a form of transport
- High strength steel alloys, such as Reynolds 531 – bikes became lighter.
- Recumbent bikes – better comfort but outlawed from racing – stalled their development
- Lightweight aluminium alloys & reliable derailleur gears – improved traditional design of Safety Cycle.
- After WWII – cycle usage declined as cheap cars available – subsequent pollution not much considered.
- Suez oil crisis, 1950s – forced many people back to bikes – cycle development took off again
- Moulton bike sparked cycling craze in UK – suited image of the swinging sixties.

- BMX (Bicycle Motor Cross) – small wheels – off road racing – popular with children
- 1980s – rise of the mountain bike – grew into the most popular bike – many specialised components developed.
- Recumbent bikes and trikes grew in popularity in the 1990s to create a niche market – good for long-distance touring – easier on the body
- 1990s and on – more exotic materials – greater weight savings – improved performance

Trains:

- Steam train – 19th century alternative to the horse and cart for transport.
- Railways systems developed world-wide, 19th century – ability for people to travel across country for first time- meant a boom for many small towns.
- Electric trains, 20th century, in urban environments, reduced pollution compared to steam trains.
- Train, important tool in WWI and WWI – supplies, movement of troops.
- After WWII, diesel train started to appear – by 1960s starting to replace steam – less pollution, greater reliability, quicker times
- More electric rail networks – further improvement of air quality.
- High-speed trains greatly cut transport times, e.g. English Channel Tunnel train faster from London to Paris than plane.
- Today, some see well-designed electric trains and light rail systems as answer to traffic congestion.

Construction and Processing Materials Over Time

Cycle

Over the years various materials have been used in cycle construction.

Timber

Timber was used in early bicycles because of a lack of suitable alternative materials. Frames were made from timber pieces that were shaped, while timber was also used for wheel construction.

Iron

Iron was used initially as a tyre on wooden wheels and in early frames, but it was replaced by steel frames and rubber tyres.

Steel

This was produced in large, cheap quantities after Henry Bessemer developed his converter in 1856. From this point, cycle frames began to use steel construction and by the 1870s steel wheels with thin steel spokes were used. Steel tubing offered good strength with a relatively low weight. Although not as light as some materials, tubing was lighter than solid rods. Cold drawn steel tubes offered the best strength for cycle frames.

Usually steel frames were joined by brazing with lugs. The lug was a small joint piece into which the tubes slid. They were then brazed in place. Only cheaper frames were welded. With newer welding techniques, however, most plain carbon steel frames are welded.

Steel was used extensively in brake and gear construction up to the 1970s when aluminium alloys started to encroach, in an attempt to save weight. Steel is still extensively used in chains and gear clusters and on many cheaper bikes all components are steel, because it offers reasonable strength, ease of fabrication and it is cost effective.

Alloy steels (as used in frames)

The term *alloy steel* refers to steels with deliberately added materials in addition to iron and carbon. Reynolds 531 was a manganese-molybdenum steel that offered a better strength to weight ratio than plain carbon steel. It was first introduced in 1935. Reynolds 531 was used in racing bikes for many years.

Chromium-molybdenum steels are also used and these once again offer superior strength to weight ratios than do plain carbon steels. Whereas Reynolds 531 was really only suitable for brazing (with lugs), chromium-molybdenum (called Cro-Mo) steels can be welded. With modern production techniques, this is an advantage, as the TIG and MIG welded frame is quicker, lighter and cheaper to fabricate than a brazed steel lug frame.

Fig 2.11: *"Steel is real", this road bicycle uses a Reynolds 631 frame, with similar weight to aluminium alloy frames, but with a more flex giving the famed ride of steel. However these steels are now more difficult to work than aluminium alloys in most mass production environments now. Note the contrast of old school leather saddle and the CFRP front forks.*

Reynolds and True Temper have released air hardening steels such Reynolds 631, 853 and True Temper OSX. The problem with welding or brazing a tube of steel that is cold rolled is that, around the weld joint, the steel is annealed and softens. Air hardening steels harden in still air to maintain strength around the welded joint. The result is an extremely strong frame with strength to weight ratios approaching many aluminium or titanium alloys.

Stainless steel

This high alloy steel was not typically used for frame construction, excepting for some Moulton bikes, but is now offered for frames in the form of a martensitic ageing stainless steel, with Reynolds 953 being an example. This stainless alloy offers UTS values up to 2000 MPa. Stainless steels are also used in the manufacture of components such as cables and pins for brakes and gears. Its corrosion resistance makes it quite desirable for these applications.

Aluminium alloys

These are now widely used in cycle construction. Reynolds offers a 6061 alloy (heat-treatable Al/Si/Mg) and a 7005 alloy (heat-treatable Al/Zn). 6061 offers excellent corrosion resistance and is more workable than other heat-treated alloys. 7005 offers greater strength but greater density than 6061. Aluminium is light but considerably weaker, so tubes are often not circular but oval, to increase the resistance to bending. Aluminium must be welded, usually using Tungsten Inert Gas (TIG) or Metal Inert Gas (MIG) methods, and offers the advantage of being relatively corrosion resistant.

Aluminium alloys are also used in the manufacture of brake and gear parts because of their lightweight nature. Brake levers and arms, derailleurs and hubs use aluminium alloys.

Titanium alloys

To a lesser extent than aluminium alloys, titanium alloys, such as 3% Al/2.5% V/Rem. Ti are finding favour in cycle manufacture, not just in frames but also in gear componentry. Titanium components and frames are usually very expensive and in frames, at least, they offer little over steel alloys like Reynolds 953, or carbon fibre reinforced polymers. Titanium must be welded using the TIG method and this must be done very carefully or there may be weld cracking.

Titanium sprockets offer a viable alternative to steel cogs but they come at a high cost and, as such, are only used on the best racing bikes.

Carbon Fibre Reinforced Polymer (CFRP)

Carbon fibre reinforced polymer is an excellent alternative to aluminium alloy or alloy steel frames. It has an excellent strength to weight ratio that is very desirable on racing bikes. The frame is moulded as opposed to fabricated and additional parts are usually placed on the frame with an adhesive.

Carbon fibre is tough and strong. When it fails, however, it happens suddenly and often catastrophically, with little or no plastic deformation to warn of imminent failure. It has become the material of choice for all mid to high level road bicycles and high end mount bicycles.

Rubber

This material was partly responsible for the growth of cycling. Solid rubber tyres were used to replace iron tyres. It was lighter and provided moderate springing. In 1888, John Boyd Dunlop developed the pneumatic tyre that made cycling even more pleasant. Today, synthetic rubber is still used in tyre construction. Rubber has also been used for suspensions on bikes. On Moulton bikes it is used for both rear and front suspension. It has the advantage of being light and also being self-damping, so no damper (a.k.a. shock absorber) is needed.

Polymers

Polymers are greatly used in the manufacture of cycles and they have found use in applications where their flexibility is a great advantage. Polymer sheaths are placed over cables, and are also used in pedal construction. They offer flexibility, are lightweight and show good resistance to deterioration caused by the weather and UV light. They are also used in cycle lights and finishing pieces.

Environmental Effects of Transport Systems

Cycles

Cycling is often looked on as one of the many solutions to environmental problems, such as pollution and the greenhouse effect. Cycling, as a form of transport, is one of the most efficient ways to travel; that is, the energy expended is used more usefully than many other forms of transport. It is non-polluting and human power is a renewable energy source.

It is perhaps not as popular as it should be as many adults abandon cycling once they get a driver's licence and the weather becomes a major issue for travel. Many people also fear riding on roads because of the dangers posed by motor vehicles, drivers who are unsympathetic to cyclists, and the absence of good cycle paths.

Trains

Trains have also had negative impacts on the environment. The construction of railways has resulted in tree felling and the levelling of land. Many railway lines also incorporate tunnels and cuttings which, when blasted, can have an adverse impact on the surrounding areas.

Steam trains produced excessive pollution, with an efficiency of only 5 to10 %. In many developing countries steam engines are still used but run on oil which produces even more smoke than coal did previously.

Electric trains also cause pollution, as the electricity must be produced somewhere! In NSW, that is usually in coal power stations, which are major contributors to the greenhouse effect. The electric train, however, does take the pollution away from urban areas where air quality is always a problem.

Diesel trains, although more efficient than steam trains, still pollute. Newer diesel locomotives, however, emit less smoke than the older ones, and modern computerised engines ensure minimum pollution for maximum power.

For passenger and freight transport, however, trains are better environmentally than road vehicles. Railway lines are narrower than freeways so have less of an impact, and they can haul many people or goods without congesting roads. Electric railways can move vast amounts of people in the city without pollution or traffic congestion.

Environmental Implications From the Use of Materials in Transport

Below is a list of different materials used in both private and public transport. The effects of using such materials are given.

Forests have been greatly affected by large scale transport developments. *Timber* was used for railway sleepers and as a fuel source for some steam locomotives. Such uses resulted in the clearing of large areas of forest. We are now feeling the legacy of this with global warming and local climate change. The removal of these forests has also had an impact on native fauna by reducing their habitat.

Steel has been the main transport material since 1856. It has found use in both plain, carbon and alloyed forms in all types of transport. The thirst for steel has seen the establishment of large steelworks, such as those at Port Kembla (NSW), which often affect the local atmosphere with the large amount of pollutants produced in working and refining the steel. Steel production requires large amounts of iron to be produced, which means iron ore must be mined. These mining operations are usually open-cut mines which involve large open pits with machinery digging down to extract the ore. As well as iron-ore, coal and limestone, are needed for the fuelling of the blast furnaces to produce the iron. Coal also has to be mined and refined to coke.

Cast iron has had a similar impact to steel but is used to a lesser extent nowadays. Essentially similar metallurgically to the iron from the blast furnace, it still requires vast amounts of iron-ore and coal and coke.

Aluminium has increased in use greatly in the last half of the 20th Century. Like iron, it is refined from an ore, bauxite, which is mined in an open cut manner, also affecting the local landscape and environment. Aluminium is refined from the ore using electricity, which in Australia, primarily comes from coal-fired power stations. The use of coal greatly contributes to greenhouse gases and as a result has a detrimental effect on our atmosphere. Aluminium refining also produces fluorine gas, a major polluter in the past, which is now controlled from reaching the atmosphere.

Polymer usage in transport systems has exploded since WWII, because polymers offer lightweight transport machinery which improves fuel efficiency. To protect the environment, the extensive use of polymers must be backed up by the recycling of old equipment, as polymers greatly contribute to landfill.

Engineering Mechanics

Simple Machines

Mechanical Advantage (MA)

The mechanical advantage of a machine is a measure of how it helps the user. Mechanical advantage in a mechanical machine is the ratio of load to effort and is found by the formula,

$$MA = \frac{L}{E}$$

MA = mechanical advantage
L = load
E = effort

The higher the mechanical advantage, the lower the effort must be for a given load. If the mechanical advantage is below one, then we have a mechanical disadvantage, which means the effort is greater than the load. Mechanical advantage is not a constant value as friction and other losses in a system affect it, meaning the theoretical mechanical advantage may be considerably higher than the practical mechanical advantage.

Velocity Ratio (VR)

The velocity ratio is the ratio of the distance the effort moves to the distance the load moves in a mechanical system. VR is represented by the formula,

$$VR = \frac{d_E}{d_L}$$

VR = velocity ratio
d_E = distance the effort moves
d_L = distance the load moves

The higher the VR the greater the distance that the user must move. Unlike MA, VR is not affected by friction and system losses. If a machine is perfectly efficient (which is not practically possible) then MA will equal VR. However the lower the velocity ratio the greater the effort that is required.

Efficiency (η)

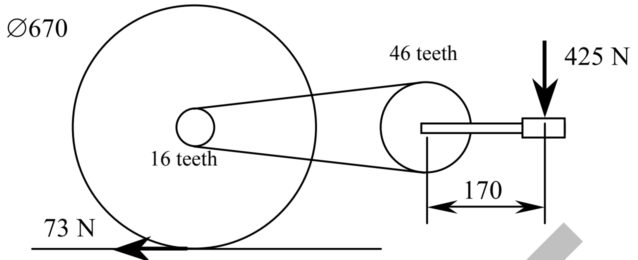
An ideal machine is one that is 100% efficient. That means all energy put into the machine is used. In reality, however, this never occurs. There is always some type of energy loss (usually as a result of friction) that results in the efficiency being below the ideal 100%. In the case of levers there may be friction in the pivots or the lever may bend slightly. VR is always the same irrespective of efficiency, since there no change in the distances the effort and load move. But MA is effected by a less than ideal efficiency; thus the MA will always be less than the VR for machines with efficiencies below 100%. The percentage efficiency is found by the following formula,

$$\eta = \frac{MA}{VR} \times 100$$

η = percentage efficiency
MA = mechanical advantage
VR = velocity ratio

Example 2.1

A single speed bicycle drive system is shown below, the tractive force at the wheel and the force on the pedals have been established experimentally. Determine the MA and VR of the bike drive system and then its efficiency.



First calculate the MA.

$$MA = \frac{L}{E}$$

$$MA = \frac{73}{425}$$

$$MA = 0.1718$$

To determine the VR we must be aware that the bicycle's gearing means the rear wheel will rotate multiple times for one rotation of the pedals.

$$VR = \frac{d_E}{d_L}$$

$$VR = \frac{d}{D \times N_{rev}}$$

$$VR = \frac{2 \times 170}{670 \times \frac{46}{16}}$$

$$VR = 0.1765$$

Now we can calculate the efficiency.

$$\eta = \frac{MA}{VR}$$

$$\eta = \frac{0.1718}{0.1765}$$

$$\eta = 0.9731$$

$$\eta = 97.31\%$$

If the drive system was poorly maintained, the efficiency would be effected as would the MA, but the VR would remain constant. The only way to change the VR is to alter the gear ratios, crank sizes or wheel size. Derailleur gears are commonly used to alter the VR of the bicycle to allow for different conditions, such as hill climbing versus fast descents.

Example 2.2

A simple screw jack is being temporarily used to raise cars for tyre changes. The thread has a pitch of 4 mm and the handle has a radius of 200 mm. If the jack has an efficiency of 50%, determine the effort required to lift the front corner of a car, which requires a load of 6 kN.

Solution

The pitch is important here because one rotation of the handle moves the scissor arms in the pitch, which is 4 mm, so each rotation of the handle moves the arms inwards by 4 mm. Therefore the pitch is the distance the load moves, and the circle described by the handle is the distance the effort moves.

$$VR = \frac{d_E}{d_L}$$

$$VR = \frac{2\pi r}{Pitch}$$

$$VR = \frac{2\pi \times 200}{4}$$

$$VR = 314.16$$

Now we can calculate the MA using the efficiency and the VR.

$$\eta = \frac{MA}{VR}$$

$$MA = VR \times \eta$$

$$MA = 314.16 \times 0.5$$

$$MA = 157.08$$

Finally calculate the effort using the MA formula

$$MA = \frac{L}{E}$$

$$E = \frac{L}{MA}$$

$$E = \frac{6000}{157.08}$$

$$E = 38.2 \text{ N}$$

We can see the jack is the complete opposite to the bicycle drive, very large MA and hence very large VR, which means your hands will move a long way operating the jack. But you are able to lift a very large object. The low efficiency is caused by friction in the mechanism, which is why the jack stays up and doesn't unwind.

Modern cars are usually provided with a scissor action jack, which is a form of screw jack, but the VR varies as the angle of the arms changes, making calculation much more challenging.

Static Friction

Static friction is friction that relates to objects that are either not moving, or are at the point of moving. If the object is moving then we are dealing with kinetic friction, which is not part of this course. We will be discussing only static friction.

The Concept of Friction and its use in Engineering

Friction is the enemy of efficiency, or the ratio of input power to output power, yet without friction, life and especially transport systems, would be very difficult. Imagine the riding of a bicycle down the road. Without friction, the first corner one turned would see the front wheels slide out and the rider lying on the ground. Stopping would also be impossible without friction. Yet at the same time friction in the drive system saps the bike of power and thus lowers efficiency.

The simple fact is, friction is essential and one must make advantage of it in traction and braking situations. Friction must be limited, however, in power transmission by lubrication and through designs that minimise internal friction like roller bearings.

Coefficient of Friction (μ)

The coefficient of friction is the ratio of the friction force compared to the normal reaction. So the formula is:

$$\mu = \frac{F_F}{R_N}$$

μ = coefficient of friction
F_F = frictional force
R_N = normal reaction

Normal Reaction (R_N)

The normal force is something that creates a great deal of confusion. It is not the weight force, which is an important point to understand. The normal reaction is a perpendicular reaction, provided by the surface on which the object is resting.

Fig. 2.12 shows the normal reaction in various situations, as well as the weight force. What is the characteristic of the weight force? What is the characteristic of the normal reaction?

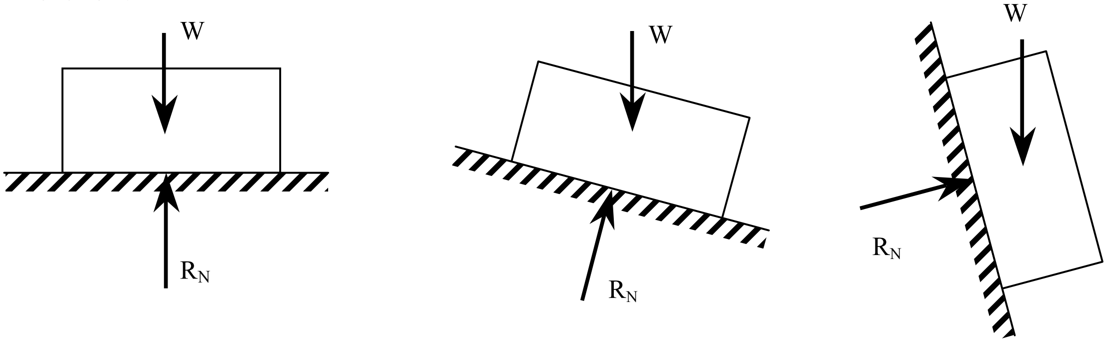


Fig 2.12: *The normal reaction is always perpendicular to the surface upon which the object rests.*

Note that the normal reaction is not equal in magnitude to the weight force in all applications. In some cases the applied forces will tend to lessen or increase the normal reaction. Fig. 2.13 shows two situations of a 10 kg box with inclined applied forces.

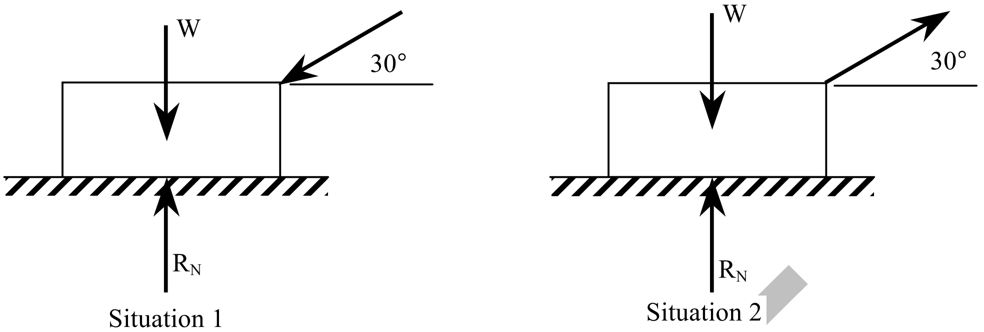


Fig 2.13: *Two 10kg boxes, one being pushed (situation 1), the other dragged (situation 2).*

In situation 1, R_N will be greater than the weight force, because of the vertical component of the applied force acting down. In situation 2, R_N will be less than the weight force as the vertical component of the applied force goes up. This is an important concept, because the larger R_N is, the higher the friction will be so it is often better to drag an object than to push down on it when sliding it.

Friction force (F_F)

Two things determine the friction force, or the frictional resistance, the force resisting the tendency towards motion between surfaces. They are the coefficient of friction between the surfaces, and the normal reaction. The higher the coefficient of friction, the higher the frictional force will be. If, however, the surfaces have a low coefficient of friction then a higher normal reaction is needed to get a high frictional force. For example, in a car the normal reaction is controlled by the mass, so good friction between the tyres and the road is dependant on the coefficient of friction between the surfaces.

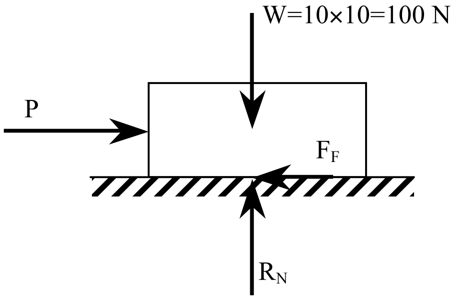
The formula for frictional force is merely a rearrangement of the formula for the coefficient of friction.

$$F_F = \mu R_N$$

Example 2.3

What will be the frictional force present when a 10 kg box is pushed just to the point of sliding by force P if $\mu = 0.5$?

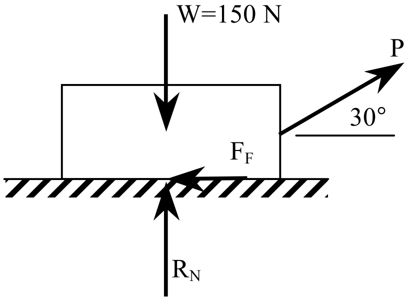
Since the applied force is vertical, R_N will equal the weight force, so $R_N = 100$ N



$$F_F = \mu R_N$$
$$F_F = 0.5 \times 100$$
$$F_F = 50 \text{ N}$$

Example 2.4

A 15 kg box is to be pulled by a force as shown. What will be the minimum value of the force to get the box to the point of sliding if μ = 0.25?



The trick in this problem is that the normal reaction (R_N) will not be equal in magnitude to the weight, since the upward force is partially taking the weight. So R_N will be equal in magnitude to the weight force minus the perpendicular component of the force P.

First find R_N by adding the vertical forces.

$$\Sigma F_V = 0$$
$$0 = P_V + R_N - W$$
$$0 = P\sin 30^\circ + R_N - 147$$
$$R_N = 150 - P\sin 30^\circ$$
$$R_N = 150 - 0.5P \text{ ———— } ①$$

Now find the sum of horizontal forces

$$\Sigma F_H = 0$$
$$0 = P_H - F_F$$
$$0 = P\cos 30^\circ - \mu R_N$$
$$0 = 0.866P - 0.25R_N \text{ ———— } ②$$

Now substitute equation ① into equation ②.

$$0 = 0.866P - 0.25R_N$$
$$0 = 0.866P - 0.25(150 - 0.5P)$$
$$0 = 0.866P - 37.5 + 0.125P$$
$$0 = 0.991P - 37.5$$
$$P = \frac{37.5}{0.991}$$
$$P = 37.84 \text{ N}$$

Limiting Friction

Limiting friction is the frictional resistance that exists just as motion is about to occur. Static frictional resistance increases up to a maximum at the point of limiting friction. After this point is passed, the frictional resistance falls and the moving surfaces exhibit kinetic friction.

Angle of Static Friction (ϕ_S)

The box in Fig. 2.14 shows that there are four forces acting on the box. If we add vectorially the frictional force and the normal force, the resultant of those two will leave three forces on the body. The angle that force makes with the normal reaction is the angle of static friction.

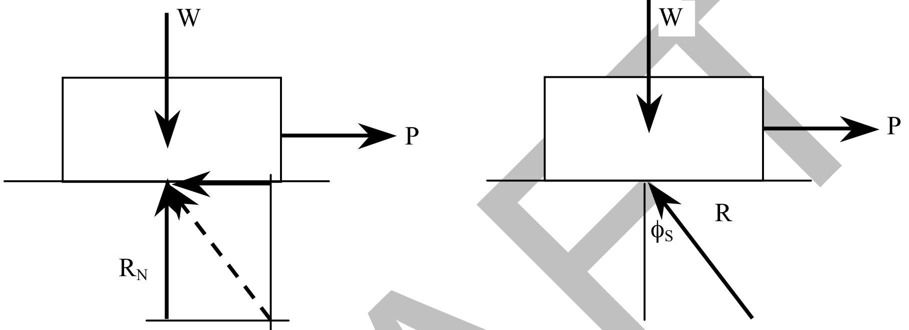
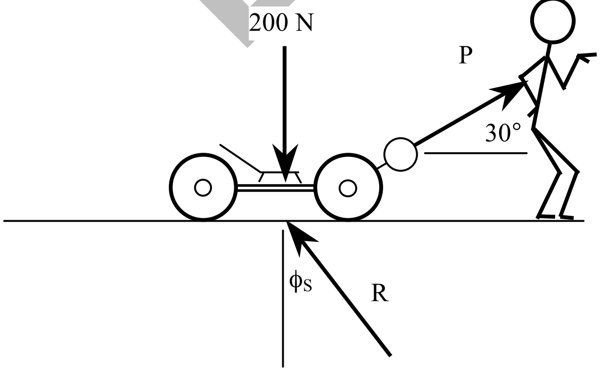


Fig. 2.14: *With the normal reaction and frictional force added together, there are three forces acting on the body, and the angle of the resultant to the vertical is the angle of static friction.*

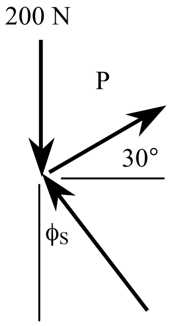
Why this angle is so useful is that at the point of sliding $\tan\phi_s = \mu$. It is then possible to find the angle of static friction, and then the force required to put an object to the point of sliding, much more easily, particularly with inclined forces. If this system is in equilibrium, these forces will be concurrent and this problem may be solved using the triangle of forces.

Example 2.5

The wheels of a recumbent tricycle have seized, so the rider must drag it home. Find the force P required to put the 20 kg trike to the point of sliding if $\mu=0.35$.



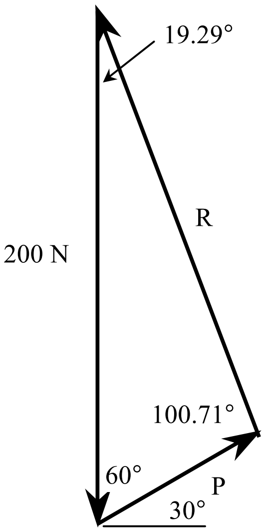
Space diagram



Free body diagram

Since $\tan\phi_s = \mu$ then $\phi_s = \tan^{-1}\mu$, therefore $\phi_s = \tan^{-1}0.35 = 19.29°$

Now draw a force polygon of the three forces on the box. Since it is not yet moving the system must be in equilibrium. Then use the sine rule to find R.



$$\frac{a}{\sin A} = \frac{b}{\sin B}$$
$$\frac{200}{\sin 100.71^\circ} = \frac{P}{\sin 19.29^\circ}$$
$$P = \frac{200 \times \sin 19.29^\circ}{\sin 100.71^\circ}$$
$$P = 67.24 \text{ N}$$

Therefore the force required to put the box at the point of sliding is 65.90 N. This problem could also be solved graphically by drawing the force diagram to scale.

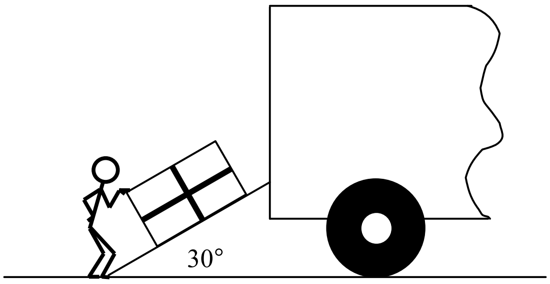
The mathematics involved in this method is far shorter than the mathematics required for Example 2.4. For this reason, many prefer to solve frictional problems using the angle of static friction.

Inclined planes

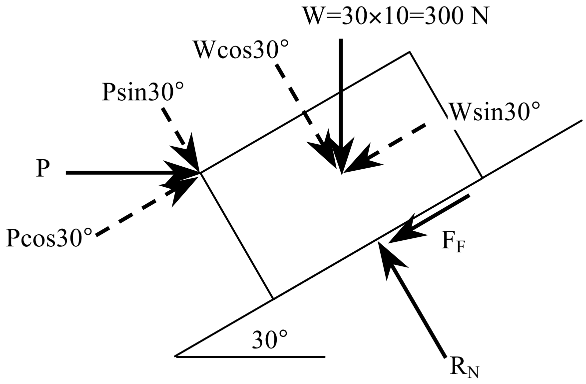
Frictional problems are well demonstrated by inclined planes and the angle of static friction is also relevant. Below is an example of the effect of friction on a box on an inclined plane.

Example 2.6

A 30 kg furniture box rests on a ramp that runs from the ground to the back of the truck. Determine the horizontal force P, the removalist needs to apply, to put the box at the point of moving, if the coefficient of friction between the box and ramp is 0.4.



First draw a free-body diagram of the box.



Add forces parallel to the plane and forces perpendicular to the plane.

$$\overset{+}{\nearrow}\ \Sigma F_{par} = 0$$

$$0 = P\cos 30° - 300\sin 30° - F_F$$

$$0 = 0.866P - 150 - 0.4R_N$$

$$150 = 0.866P - 0.4R_N \qquad \text{———} \ ①$$

$$\overset{+}{\nwarrow}\ \Sigma F_{perp} = 0$$

$$0 = R_N - P\sin 30° - 300\cos 30°$$

$$R_N = 0.5P + 259.81 \qquad \text{———} \ ②$$

Substitute equation ① into equation ②

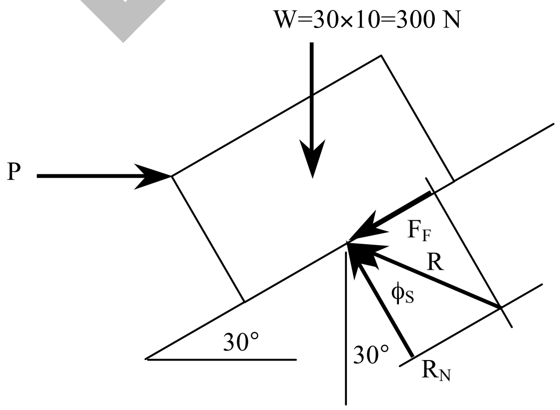
$$150 = 0.866P - 0.4(0.5P + 259.81)$$

$$150 = 0.866P - 0.2P - 103.92$$

$$0.666P = 253.92$$

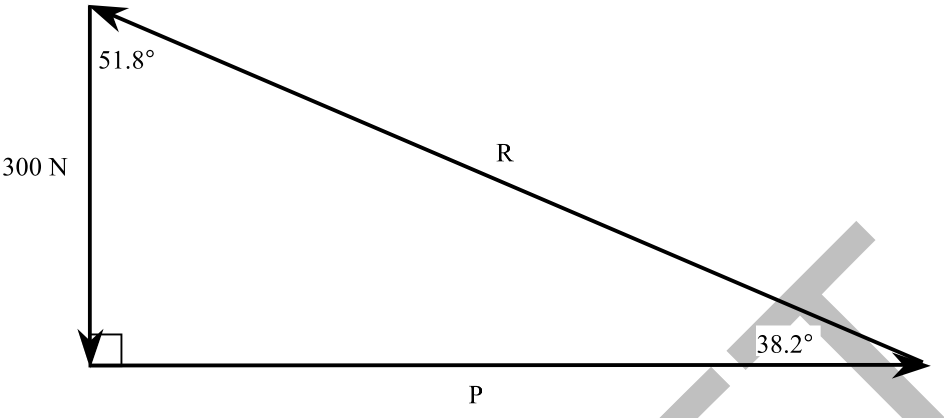
$$P = 381.25 \text{ N}$$

This problem could also be solved using the angle of static friction as is shown below.



Now $\phi_s = \tan^{-1}0.4 = 21.8°$

Draw the force polygon and use the trig ratios (since it is a right angle triangle) to find P. Note that the angle of friction is 21.8° from the normal reaction, but the normal reaction is inclined at 30° to the vertical, so the angle the reaction makes with the vertical is 21.8°+30° = 51.8°.



$$\tan 51.8° = \frac{P}{300}$$

$$P = 300 \times \tan 51.8°$$

$$P = 381.25\ \text{N}$$

The second method is far easier than the first.

Angle of Repose

If an object is placed on a flat surface with no net force acting upon it, it will not move, i.e. it is in equilibrium. If the surface is raised at an angle to become an inclined plane (Fig 2.16) the weight force will have two components, one acting down the plane (Wsinθ) and one acting perpendicular to the plane (Wcosθ). As the angle increases Wsinθ will increase, while Wcosθ decreases. At 45° they will be equal. At a point the value of Wsinθ will become larger than the frictional force opposing motion and the object will slide down the plane. At that point of limiting friction, F_F will equal Wsinθ and R_N will equal Wcosθ.

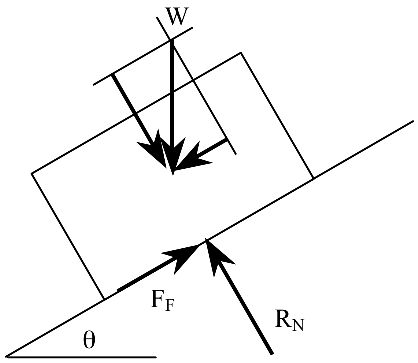


Fig. 2.16: *A box resting on an inclined plane*

Mathematically we can express it as follows:

$$\mu = \frac{F_F}{R_N}$$

$$\mu = \frac{W\sin\theta}{W\cos\theta} = \tan\theta$$

$$\tan\theta = \tan\phi \; (\because \mu = \tan\phi)$$

$$\therefore \theta = \phi$$

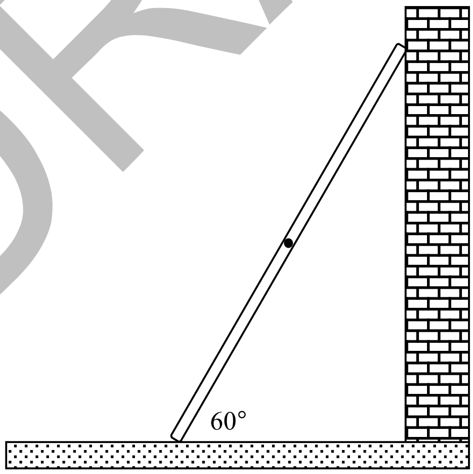
Therefore at the point of limiting friction, there will be an angle where the angle of static friction will equal the angle of inclination of the plane. This angle is called the *angle of repose*. The angle of repose is important in the design of equipment where items must slide of flow.

Friction with Ladders

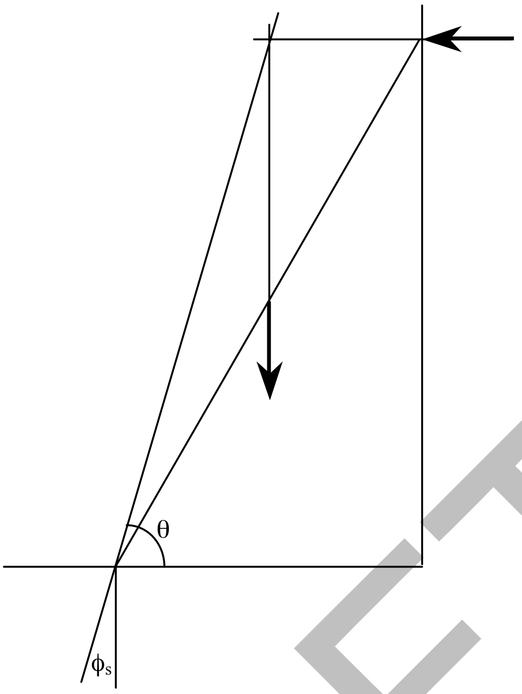
Ladders are a good example of friction action. In most ladder problems the calculation is simplified by considering the wall to be smooth (i.e. friction free). In reality this isn't true and some problems may provide a coefficient of friction for the ladder and the ground and also the ladder and the wall. The example below details

Example 2.7

A uniform 4 m ladder is shown; it rests against a smooth wall and a rough floor. If the ladder has a mass of 10 kg, determine the coefficient of friction needed between the ladder and the ground so the ladder will not slip. Consider the wall to be smooth.



Because the wall is smooth the reaction at the wall will be perpendicular to the wall, so the direction is known. The weight will be vertical which leaves only the third force, the reaction at the ground. We can see this is a three force rule problem, so we can determine the ground reaction's direction using the three force rule.



By measuring the angle of the line representing the third force's line of action we can determine that θ is approximately 73°. Therefore ϕ_s will be 17°.

$$\phi_s = \tan^{-1}\mu$$
$$\mu = \tan\phi_s$$
$$\mu = \tan 17°$$
$$\mu = 0.31$$

This problem can also be solved analytically but the author has chosen to model the quicker graphical solution.

Work, Energy and Power

The concepts of energy, and power were first investigated in Volume 1 (pp. 101-104). Various forms of energy, work and power were introduced and now these concepts will be reviewed.

Work

Energy and work are closely related concepts. It is prudent to discuss work prior to discussing energy. Work in engineering terms is a vastly different concept from the layperson's use of the term work. Work in engineering occurs when a force causes motion, which may either be a bike moving down a road or deformation caused by a tensile or compressive load. Hence, work is done when a force causes a bike to move, and it is also done when we squeeze the bikes brake pads against the rim for braking. If no motion/deformation occurs, no work is done. The value for work is found by multiplying the value of the force by the displacement as the object moves, and is shown by the formula below.

$$W = Fs$$

W = work (J)
F = force (N)
s = displacement of the object (m)

The unit for work is the Joule (J). One Joule is equivalent to one Newton moved one metre. Since force and displacement are vector quantities, so is work. As a vector there can be negative and positive work. Positive work occurs when work is done in the direction of the applied force and negative work occurs when the work is done in the opposite direction to the applied force.

If the force doing work is at an angle to the horizontal, and the object is moving horizontally, the only part of the force doing work is the horizontal component. Hence we need to multiply the horizontal component of the force by its displacement. Another form of work may be done on the box when the vertical component causes small deformations. This work is usually very small and therefore ignored.

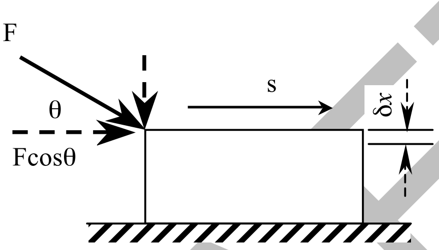


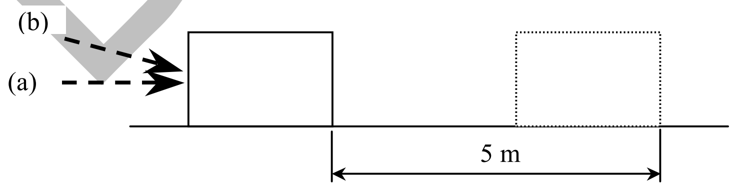
Fig 2.15: *The work done on this box is the product of the displacement (s) and the horizontal component of the force (Fcosθ). Another type of work is the deformation δx that may be caused by the vertical component of F.*

$$W = Fs\cos\theta$$

W = work (J)
F = force (N)
s = displacement of the object (m)

Example 2.8

A box containing a bicycle is slid 5 m by a 200 N force as shown on a smooth surface. What is the work done if the force is (a) horizontal and (b) if it is at an angle of 15° above the horizontal? (Ignore any box deformation.)



(a)
$$W = Fs\cos\theta$$
$$W = 200 \times 5 \times \cos 0$$
$$W = 1000 \text{ J}$$

(b)
$$W = Fs\cos\theta$$
$$W = 200 \times 5 \times \cos 15$$
$$W = 965.93 \text{ J}$$

Therefore the inclined force means less work is being done, as some work is expended in trying to deform the box. If the surface had friction present, then the vertical component would increase the frictional resistance and result in even less work being done.

Energy

In Volume 1, module 3 (pp. 101-104) the concept of energy was discussed. Here we will specifically look at two types of mechanical energy, potential energy and kinetic energy. Energy and work are also closely linked, and the unit for energy is also the Joule.

Potential Energy

Potential energy may be considered as stored energy with the potential to do work. For example, consider a brick weighing 3 kg, held 2 m above the ground. The potential energy will be a measure of its ability to do work from that position. If the brick is dropped from a height of 1 m into soft ground, when it hits, it will do work, i.e. splash mud and make an impression. The mud cannot move unless work is done on it. This work comes from the potential energy that the brick possessed before it fell.

The formula for potential energy (PE) takes into account the mass, gravity and height above a frame of reference.

$$PE = mgh$$

PE = potential energy (J)
m = mass of object (kg)
g = acceleration due to gravity (ms^{-2})
h = height (m)

Kinetic energy

Kinetic energy is energy that a body possesses as a result of its motion. If a body has any velocity then it will possess an amount of kinetic energy which is proportional to the mass, and the velocity squared. Small variations in velocity, therefore, have a greater effect than small variations of mass. The kinetic energy will be equal to the work required to stop the object.

The formula for kinetic energy (KE) is as follows:

$$KE = \tfrac{1}{2}mv^2$$

KE = kinetic energy (J)
m = mass of object (kg)
v = velocity of object (ms^{-1})

PE v's KE

These two quantities are closely linked, as can be seen in transportation devices such as cycles. Fig 2.16 shows a simple drawing of a folding bicycle and rider. As the bike rolls down the slope, its KE will increase, but this will be at the expense of the PE, as energy cannot be created or destroyed but merely converted from one form to another. The reverse is also true; if the bicycle is travelling along a flat road and coasts up a hill, the loss in KE when it stops, will be equal to the PE it has gained. The only way further PE can be gained in climbing the hill is by the rider doing work on the pedals.

In reality the loss in PE and the gain in KE is never exactly the same. The reason is that frictional resistance and air resistance do negative work that opposes motion. A small amount of noise energy would also be given off.

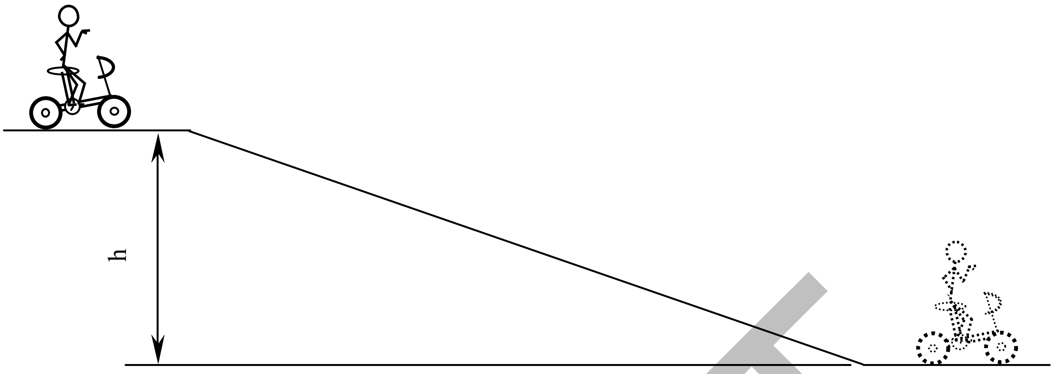


Fig. 2.16: *A folding bicycle and rider is on a road at the top of a hill. They possess potential energy because of the height above the lower portion of the road. This potential energy is lost as they coast down the hill, until at the bottom all the potential energy has become kinetic energy.*

For any object, the initial PE and KE, combined with any positive or negative work will be equal to the final PE and KE combined. Mathematically this may be written as:

$$PE_i + KE_i \pm W = PE_f + KE_f$$

Consider the tricycle example in relation to numbers in Example 2.6.

Example 2.9

The folding bicycle in Fig 2.16 has a mass of 12 kg and the rider weighs 80 kg. What will be the velocity of the bicycle after it coasts to the bottom the hill, if h = 20m and friction and air resistance is ignored?

There are two ways to solve this problem.

Method 1 involves calculating the PE and then determining the velocity.

$$PE = mgh$$
$$PE = 92 \times 10 \times 20$$
$$PE = 18400 \text{ N}$$

$$KE = \tfrac{1}{2}mv^2$$
$$v^2 = \frac{2KE}{m}$$
$$v = \sqrt{\frac{2KE}{m}}$$
$$v = \sqrt{\frac{2(18400)}{92}} (\because KE = PE = 18400 \text{ J})$$
$$v = \sqrt{400}$$
$$v = 20 \text{ ms}^{-1} = 72 \text{ km/h}$$

Method 2 involves algebraic methods to simplify the problem initially.

$$
\begin{aligned}
PE &= KE \\
mgh &= \tfrac{1}{2}mv^2 \\
gh &= \tfrac{1}{2}v^2 \\
v^2 &= 2gh \\
v &= \sqrt{2gh} \\
v &= \sqrt{2\times 10\times 20} \\
v &= \sqrt{400} \\
v &= 20\ \text{ms}^{-1} = 72\ \text{km/h}
\end{aligned}
$$

Method 2 is really the better method as one is less likely to make mistakes in writing down letters, and no calculation errors can slip through until the end.

The final velocity of 72 km/h is fast and somewhat unrealistic. In reality, friction and air resistance would do negative work to lower this figure.

Now we can make the example a little more realistic is we consider a combination of air resistance, friction and rolling resistance causing some negative work. It is only a little more realistic because air resistance is actually a function of velocity so as the bike goes faster the air resistance increases.

Example 2.10

The same 12 kg bicycle and 80 kg rider are at the top of a 20 metre high hill and it is 300 m to the bottom. If the combined resistance to motion is 40 N, determine the velocity of the bicycle after it coasts to the bottom of the hill.

$$
\begin{aligned}
PE_i + KE_i \pm W &= PE_f + KE_f \\
mgh + 0 - Fs &= 0 + \tfrac{1}{2}mv^2 \\
92\times 10\times 20 - 40\times 300 &= \tfrac{1}{2}\times 92\times v^2 \\
46v^2 &= 18400 - 12000 \\
v &= \sqrt{\frac{6400}{46}} \\
v &= 11.80\ \text{ms}^{-1} \\
v &= 42.46\ \text{km/h}
\end{aligned}
$$

This is a more realistic figure for a bike coasting down the hill than in the simpler example. It can be seen the distance the bike travelled was necessary to calculate the negative work. Alternatively the problem could have given the angle of the hill and the distance travelled, the height is then found using trigonometry.

Vehicles loss of Kinetic Energy – Or Energy Wasted v's Energy Used

When a vehicle is moving it has kinetic energy. The brakes must do negative work to retard the vehicle. Currently, on cycles, only friction brakes are available. They convert kinetic energy into heat energy. This system is really a waste of the energy the rider has expended climbing the hill initially. Cars can use engine braking where the motor resists the motion of the car when the accelerator is released, while trucks and buses may have compression braking or retarders, using magnetic methods, to slow a vehicle. All these methods mean that lost kinetic energy is lost for good.

When braking, trains can use the electric motors at the wheels to produce electricity by using the motors, as generators. In an electric train the current is passed back into the overhead lines, while in a diesel electric train the current is fed back through large resistors. Electric cars can also use a similar feature. Electric motors driving the wheels can act as generators, which will tend to slow the vehicle and feed the produced electricity into the battery for later use. In these systems the kinetic energy is converted into a useful form, to help brake the vehicle.

Power

Power is defined as the rate at which work is done. The unit for work is the Watt (W), which is equal to one Joule per second. Power is useful in comparing the outputs of different engines in vehicles. For example, two trucks may do 30,000 J of work but if one does it in half the time of the other then it has double the power of the other engine.

$$P = \frac{W}{t} = \frac{Fs}{t} = Fv$$

P = power (W)
W = work (J)
t = time (s)
F = force (N)
s = displacement (m)
v = velocity (ms^{-1})

Torque

Torque should be mentioned because of its links in engines to power. The torque of a motor is the turning moment that the motor produces. The higher the torque figure, the greater the turning moment. Torque is closely related to moments, and torque is found using the same formula and has the same units. Moments relate to statics, while torque is used in dynamics. Torque is a measure of the forces that a given engine can develop and use in moving a load.

$$\tau = Fd$$

τ = torque (Nm)
F = force (N)
d = perpendicular distance from the force to the pivot (m)

When a motor is connected to a gearbox it is the torque, not the power, that is varied by the gearbox. Trucks typically have high torque engines so large loads can be hauled. The power of an engine is proportional to time rate of change of torque.

Power and Torque Figures – or, "Wow that car must be fast!"

Power figures are regularly quoted in transportation publications as an indicator of how effective a motor is. This figure is only one indicator of how a motor performs. Another is the torque figure which indicates the turning moment of the motor.

The power alone does not decide how fast a vehicle will be. A lighter, less powerful car may have a better ratio of power to weight than a heavy car and hence perform better. Gearing also has an impact on performance with the different gear ratios important determinants. A high torque figure means that the vehicle climbs and pulls loads well.

Finally the power figure given for a motor is the power at the crankshaft. After the gearbox, differential and drive shafts are taken into account, the power figure is considerably lower, so power at the wheels may be 50% less than that at the crankshaft. This is because no engineered device is ever 100% efficient and devices like gearboxes often sap considerable power with friction.

Example 2.11

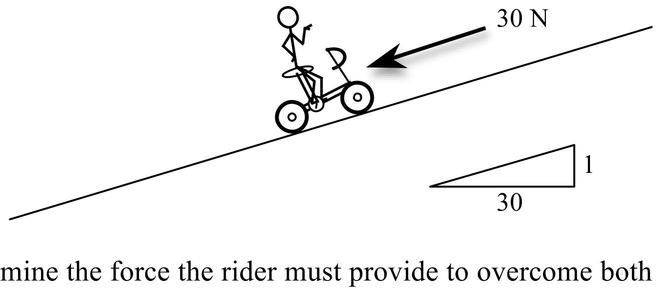
A car is travelling at 110 km/h on a level section of freeway, if the total resistance to motion is 1.1 kN, determine the power the motor must expend to keep the car travelling at this velocity.

Remember we must convert the 110 km/h velocity into 30.56 ms^{-1}.

$$\begin{aligned} P &= Fv \\ P &= 1100 \times 30.56 \\ P &= 33611.11 \text{ W} \\ P &\approx 33.6 \text{ kW} \end{aligned}$$

Example 2.12

A bicycle and rider are ascending a hill of grade 1 in 30. Determine the power the rider needs to expend to maintain a velocity of 20 km/h if the total resistance to motion is 30 N.



We must determine the force the rider must provide to overcome both the resistance to motion and the force of his/her mass down the hill, which is mgsinθ.

The force provided by rider, F_T, against weight and resistance is found by summing forces parallel to the incline.

$$\overset{+}{\nearrow}\ \Sigma F = 0$$

$$0 = F_T - mg\sin\theta - F_R$$

$$F_T = mg\sin\theta + F_R$$

$$F_T = 92 \times 10 \times \sin 1.91^\circ + 30$$

$$F_T = 60.65 \text{ N}$$

Now determine the power needed with a velocity of 20 km/h, which is 5.56 ms^{-1}.

$$P = Fv$$

$$P = 60.65 \times 5.56$$

$$P = 336.94 \text{ W}$$

Engineering Materials

Testing of Materials

Hardness Tests

Table 2.1: *Hardness Tests*

Hardness Test	*Operation*
Brinell	A hardened steel ball is forced into an object under specified load conditions. The diameter of the ball is dependent on the test piece's thickness. The hardness number is determined by measuring the depth and surface area of the impression and using a formula, which also incorporates the applied load.
Vickers	Here a small square pyramid is forced into a test piece under specified load conditions; the hardness number is derived from a formula that contains the load and area of the indentation. More useful for thin metals than the Brinell test as the loads are lower and the indentor smaller.
Rockwell	This is a simple test that dispenses with the use of a formula. A diamond cone (or sphere) is forced into a test piece under specified load conditions and a reading is displayed on the dial. There are different scales for different loads depending on the material tested. Rockwell hardness testers are the most common hardness testers in schools as they sued to be provided to NSW high schools.
Shore Scleroscope	This test involves a small striker in a tube. The tube is placed over an item and the striker is dropped, the height the striker rebounds from the item is a measure of the hardness. Soft items will absorb more of the energy of the falling striker giving a lower rebound than hard materials

Impact Tests

Impact tests are carried out to determine the notch toughness of a material. This is done by subjecting the material to a concentrated shock load. Tough materials will not break as easily as a brittle material.

There are various ways to perform an impact test. The two most common standard methods are the Izod and Charpy Tests, while a small laboratory system is the Hounsfield balanced impact tester.

The Izod and Charpy Tests are essentially the same except the test piece is held differently. The test involves a large pendulum being raised to a specified height to give it potential energy (PE). Upon release, it loses PE and gains kinetic energy (KE). At the bottom of its swing it will strike the test piece, with some KE absorbed in breaking the test piece. After passing the test piece, the pendulum will swing up in height gaining PE and losing KE, until all energy of swing is used up. The height reached is recorded. The difference between the initial height and the final height is proportional to the energy absorbed when breaking the test piece.

The Hounsfield balanced impact tester is smaller, and used for schools and colleges or in industry, as a transportable machine. It uses two pendulums, with one solid one swinging through the other hollow pendulum. The result is double the impact that would be had with a single pendulum, thus allowing a smaller tester. The energy required to break the material, is merely read from a scale on the pendulum pivot.

The test piece used in all these testers is a small cylinder with a V notch placed in it to concentrate the stress and provide a place to promote crack propagation. In the Hounsfield test, the notched piece is held in the solid pendulum, so the outer pendulum hits both ends. In the Izod test, the notched bar is held vertically, with the upper end free, ready to be struck by the pendulum. The notch is placed so it faces the pendulum. In the Charpy test, the notched bar is held horizontally at both ends. The pendulum strikes it in the middle, with the notch facing away from the pendulum.

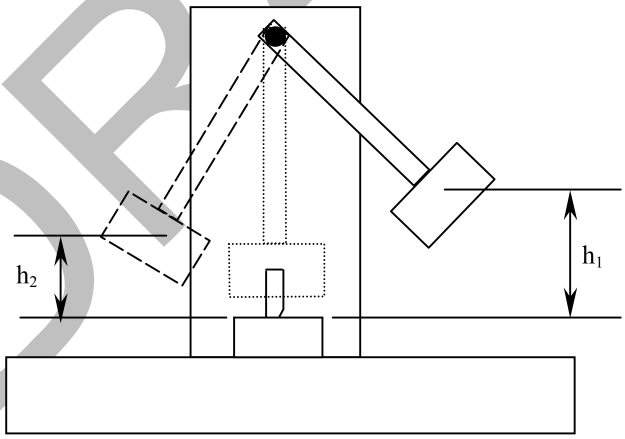


Fig. 2.17: *An Izod test, with the various pendulum positions shown. At the solid position, PE is a maximum; at the dotted position, PE is zero, while at the dashed position, PE is equal to the initial PE minus the energy required to break the notched piece.*

Heat Treatment of Ferrous Metals

The properties of steels can be greatly altered by the way they are cooled after heating. This section outlines some of the possible modifications made to steels through heat treatment.

Annealing

There are two basic types of annealing – process annealing and full annealing.

Process annealing involves the heating of a steel with less than 0.3%C to a temperature usually between 550 and 650°C. The purpose of this is to relieve any stress from distorted grains caused by cold working or deformation. The ferrite grains will reform as unstressed grains, while the pearlite remains in the deformed state

Full annealing involves heating either hypo-eutectoid steels or eutectoid steels into the austenite region at a temperature of about 40°C above the upper critical temperature[1]. The steel is then cooled very slowly, usually in a furnace, with the result being a softer, coarser grained steel than previously existed. All grains will be in an unstressed state.

Normalising

Normalising involves heating a steel up into the austenite region well above the UCT. When the structure is all austenite, it is then cooled in still air. The process takes less time than full annealing and produces a finer grained structure and hence a stronger steel.

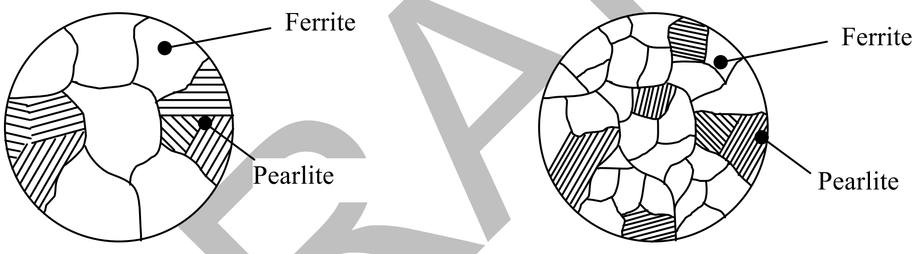


Fig 2.18: *(a) Annealed low carbon steel and (B) normalised low carbon steel. Note the smaller Ferrite grains and finer Pearlite in the normalised steel.*

Hardening and Tempering

The ability to harden steels is one of their most desirable characteristics. This is one of the many reasons why steel is such a versatile material.

Hardening

The concept of hardening steels and the resulting martensite was first covered in Volume 1 (p 110). A brief recap is given here. If a steel is heated until it is austenite in structure and quenched rapidly, the transformation from face centred cubic (FCC) austenite to body centred cubic (BCC) ferrite is not given enough time to occur fully and the steel becomes trapped in between as Body Centred Tetragonal (BCT) martensite. This new structure can be exceedingly hard but quite brittle. Martensite will form in any steel with carbon composition greater then 0.03%. Low carbon

---

[1] The upper critical temperature (UCT) is a temperature for each steel composition at which the steel fully transforms to austenite. The value UCT is composition dependent and ranges from 910°C for 0.01%C steel then down to 723°C for 0.8% C steel.

martensite is soft and does not become really hard until the carbon composition is in the range of 0.4 and 0.8%.

Air Hardening

If a steel has nickel and chromium added in small amounts (<5%) then it will have air hardening properties. This means that if it is heated to red hot and cooled in still air, martensite will form. Usually molybdenum is also added to reduce brittleness.

Tempering

A fully hardened steel has limited usefulness as it can only be used in applications where hardness is the only requirement. If hardness and toughness are both required, a fully hardened steel is no longer useful. It is, however, possible to sacrifice some hardness and gain better toughness through tempering. This involves taking a hardened steel and heating it to a temperature between 200 and 600°C. A low tempering temperature will produce high hardness and moderate toughness while a higher tempering temperature will have the opposite effect.

Although not as hard as a fully hardened steel, tempered steels are still considerably harder than annealed or normalised steels.

Microstructural Changes

One obvious feature of heat treated steels relates to grain size and structure. Annealed steels tend to be soft with moderate strength, in part due to the coarse grain structure that results. Normalised steels tend to have a finer grain structure which results in higher strength.

By hardening a steel, the grain structure is highly stressed and has an acicular appearance, with the result being high hardness and brittleness. Tempered steels tend to have a very fine structure of carbide particles in a ferrite matrix, which gives toughness and moderate hardness.

A B

Fig 2.19: *(A) 0.8% normalised plain carbon steel. (B) 0.8% plain carbon steel hardened to give martensite. (from* Experimental Materials Science*, Gibson and Taylor)*

One structure produced by heat treatment that cannot be produced by normal cooling is *bainite*. Bainite has a structure consisting of very fine cementite particles in a ferrite matrix. Bainite, in fact, is similar to pearlite in overall composition but instead of layers of cementite it consists of tiny particles. Bainite is formed by a process called austempering where the austentic steel is quenched to around 400°C and held there until that temperature exist throughout, then it is quenched to room temperature. The resulting structure is similar in performance to tempered martensite, but has significantly greater resilience.

Bainite at times occurs when the quench rate is not fast enough to produce martensite as some cementite can form. If quenching is of a moderate speed then there may be a mixture of martensite and bainite. If the quench rate slows further then the result will be fine pearlite.

Changes in Properties

There are primarily three ways we can alter the properties of steels. Steels are greatly effected by the addition of carbon, and only small amounts of carbon are needed to achieve the changes. This is because carbon and iron form an interstitial solid solution. In Chapter 3 Volume 1 a chart clearly showed the effect carbon content had on hardness, tensile strength, ductility and toughness. This chart should be reviewed to ensure students understand the clear effect carbon has.

Properties can be further changed by heat treatment; iron's allotropic nature means that by varying the rate of cooling we can bring about vastly different properties in a steel. The hardening and tempering of steel is a process that cannot be repeated with most other alloys.

Finally properties can be further altered by alloying steels. Alloy steels such as stainless steel, high speed steel, HSLA steels and "cro-moly" steels were all outlined in Volume 1. Often by adding alloying elements we bring about improved properties without the detrimental effects of high carbon content. Air hardening steels mentioned earlier in the chapter are only possible with the addition of nickel and chromium, no plain carbon steel can achieve this property.

Manufacturing Processes for Ferrous Metals

When materials are formed, the formative process may have a large impact on the properties of the final article. Below is an outline of some of the effects of manufacturing processes on the materials' properties.

Forging

Forging may be defined as the shaping of a metal through the use of force. Forging may be carried out above the recrystallisation temperature (hot forging) or below it (cold forging or pressing). Forging can take a variety of forms, the simplest type being that which a blacksmith does against an anvil. Forging may draw out a metal while reducing its cross-sectional area (drawing); reduce its length while increasing its cross-sectional area (upsetting), or it may force the metal into dies to take the required shape, as in drop forging.

All of these methods produce grainflow in the metal that follows the shape of the object. This improves the strength of the finished article, as against a machined part where the grainflow may cause planes of weakness.

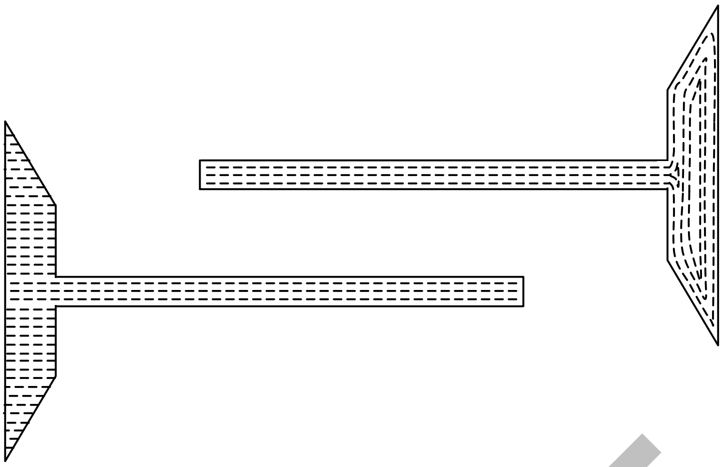


Fig. 2.20: *The macrostructure of two automotive valves are shown.. The upper one is forged while the lower one is machined from a hot rolled bar. Note how the grain flows to the shape of the forged valve.*

Rolling

Rolling can be done either above the recrystallisation temperature, (hot rolling), or below the recrystallisation temperature, (cold rolling). The recrystallisation temperature is that temperature above which deformed (stressed) grains in metal will re-nucleate and grow into annealed grains (stress-free). Unstressed grains will not re-nucleate, but they will grow.

Hot rolling

Hot rolling is used extensively in the production of sheets, strips, bars and rods of metal. Ingots of the required metal are passed through successive rollers to produce the required thickness of metal. When passed through the rollers the metal's crystal structure is deformed. Since it is above the recrystallisation temperature however, it recrystallises into an unstressed form.

The *advantages* of hot rolling are:
- less stress on the machinery when compared to cold rolling
- an unstressed finished product.

The *disadvantages* are:
- that the final products are not as dimensionally accurate
- it will have a black oxide layer over the finished product.

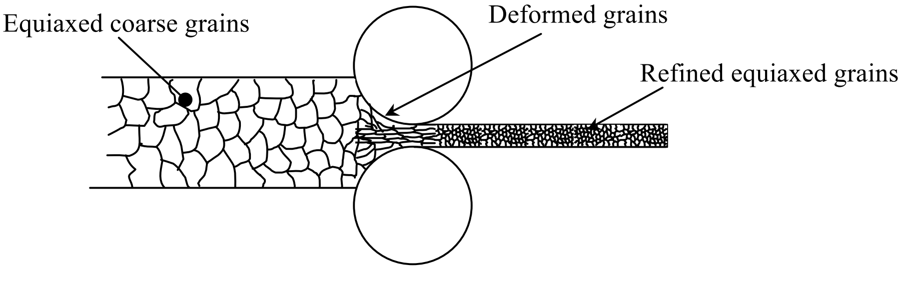


Fig. 2.21: *Hot rolling will produce a fine, but unstressed grain structure*

Cold Rolling

As a result of being carried out below the recrystallisation temperature, cold rolling will produce a slightly different final product. The procedure is essentially the same but the rollers and machinery are more heavily built, as larger forces are required. The finished product will have distorted grain structure that will produce a harder and stronger final product. These properties come at the expense of ductility and malleability.

The *advantages* of cold rolling are:
- a harder final product that is more dimensionally accurate
- a more presentable product because of the lack of oxides.

The *disadvantage* is greater cost because of the heavier machinery needed.

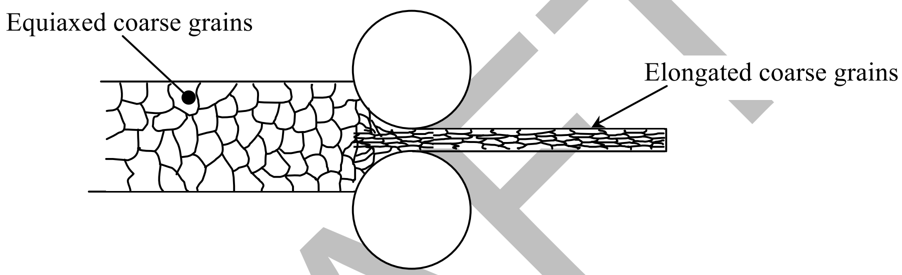


Fig. 2.22: *The final structure has a distorted grain.*

Casting

Casting comes in a variety of forms. In Volume 1 we only looked at Die Casting and Investment Casting. Now we shall review those and introduce some more.

Ingot Casting

Many metals are not cast to their final shape. Often metals are cast into a large block, or ingot, to be shaped into something by rolling, or some other mechanical means. Ingot casting is done by pouring a molten metal into a large tapered metal mould. Upon solidification, the mould is lifted away and the ingot is ready for shipment. Ingot casting was used extensively, but nowadays it has been replaced by more mechanised methods of continuous casting.

Continuous Casting

This method of casting allows for the rapid production of simple cross-section products like bars and strips. The molten metal is poured into a water-cooled ingot with a sliding bottom. Once the bottom has solidified, the base moves down at a rate that allows the molten metal above it to solidify. The resulting long metal strip is cut to the required length. This casting method is used in large plants because of its rapid speed and cost effectiveness on large runs.

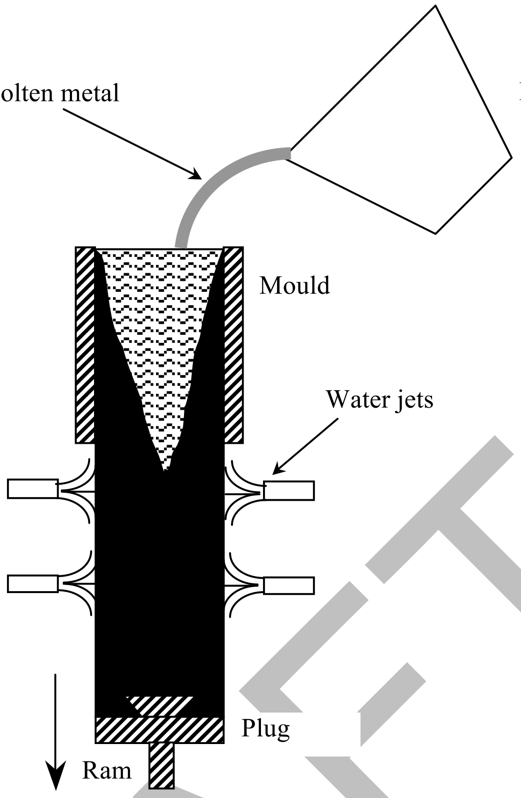


Fig. 2.23: *A method of continuous casting. The water blasts cool the metal as the moving base slides downwards.*

Sand casting

This is one of the commonest casting procedures. Sand, with a binder, so it holds together, known as green sand, is packed around a pattern of the finished product. The mould is in two halves to allow the pattern to be removed. Once the pattern is removed, and the two halves are assembled a cavity is left for molten metal. Once the metal solidifies, the sand is removed, and reconstituted, ready to be used again. The procedure is outlined below.

In Step 1, the lower box, ‘the drag’, is placed on a board with the pattern inside. “Green” sand is then packed tightly around the pattern. The drag is inverted and the top box, “the cope”, is placed on top. By Step 2, the cope is filled with sand and there are pins for the riser and runners in place. At Step 3, the cope and drag are separated, the pattern, riser and runner pins are removed and the boxes are reassembled. Step 4 sees the molten metal poured into the runner pin until the riser and runners are filled. At Step 5, the casting is allowed to solidify and any shrinkage caused by contraction is alleviated by molten metal from the riser pin running into the casting. Once solidified, the casting is removed and the runner and riser parts are ground off.

The process can be automated, and it finds great use in the automotive fields. Engine blocks and heads are usually sand cast. The advantages of sand casting are cheap and easy castings and good final grain structure. The disadvantages are that the final surface finish is poor and inaccurate. Hence machining is essential for precision parts.

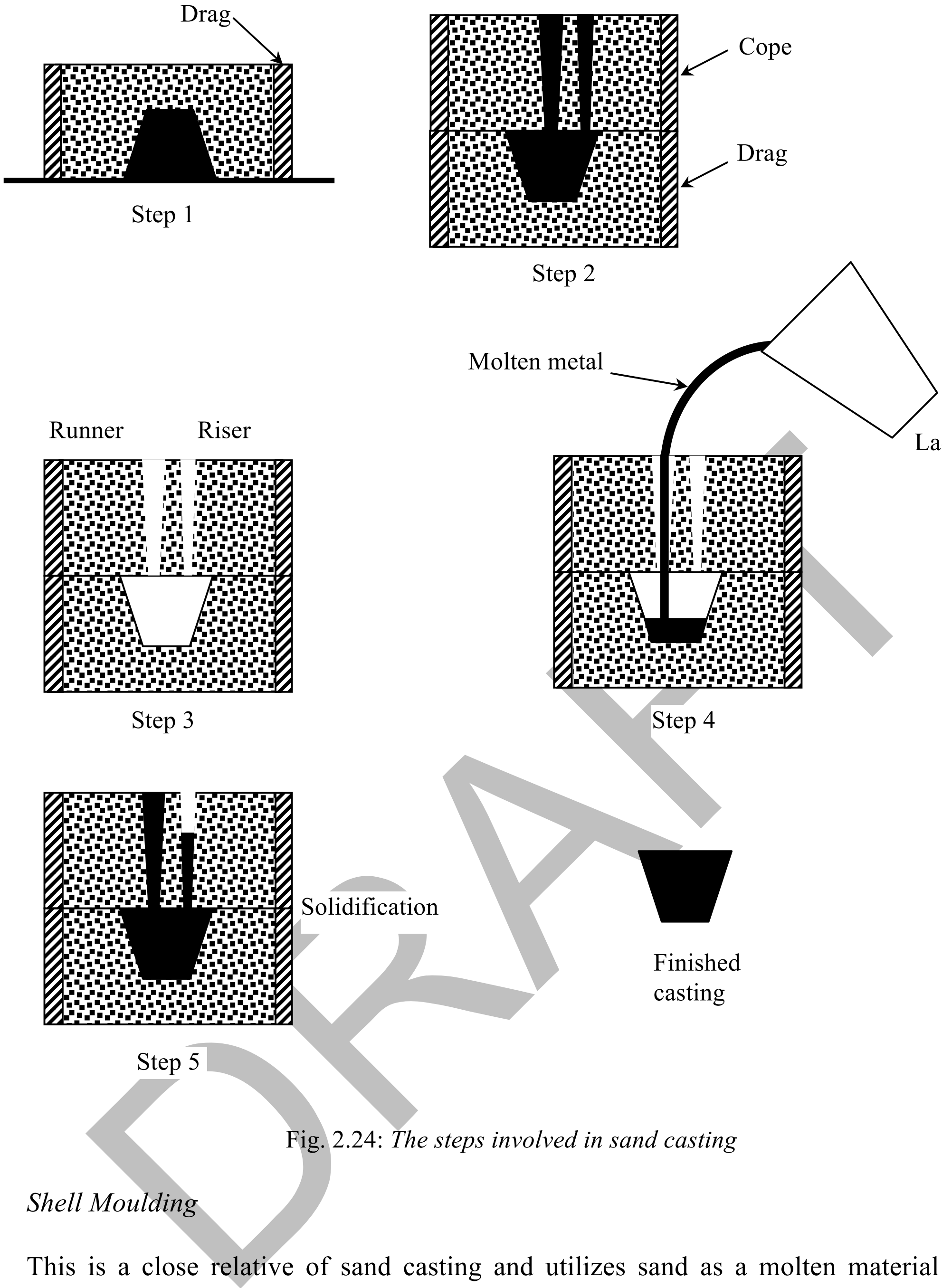
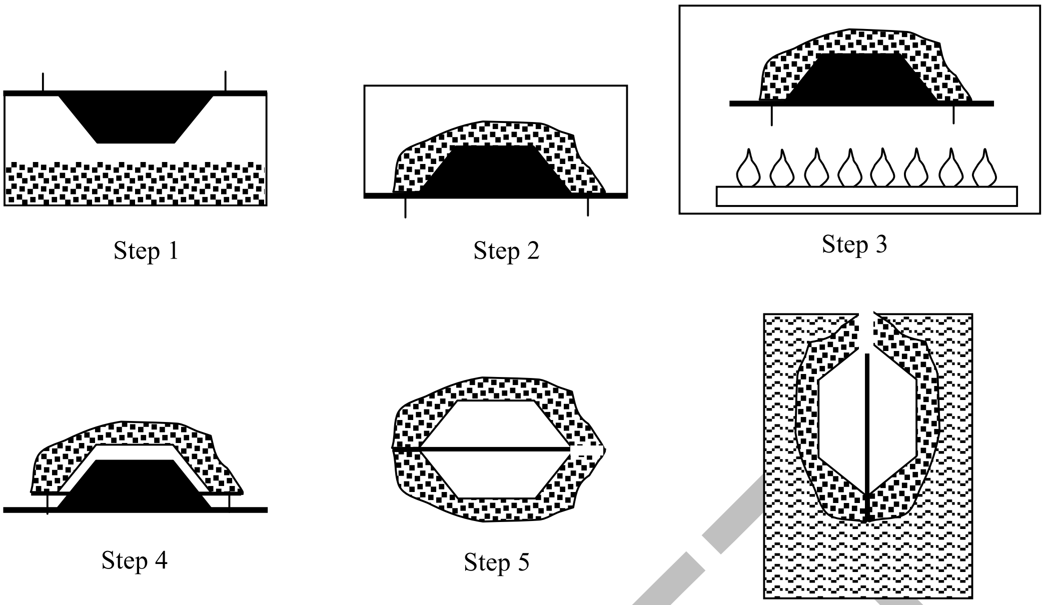


Fig. 2.24: *The steps involved in sand casting*

Shell Moulding

This is a close relative of sand casting and utilizes sand as a molten material in a different way. The steps are outlined below.

In shell moulding, a heated pattern plate is placed over a dump box (Step 1). At the bottom of the dump box is a mixture of sand and a thermosetting resin. The dump box is inverted and the sand and resin mix drops over the heated pattern plate (Step 2). The heat from the pattern plate partially sets the resin, holding the sand together. The half mould and pattern plate are then heated in an oven at 315 °C to ensure the resin is fully cured (Step 3). The cured half mould is then ejected off the pattern by small ejector pins (Step 4). The two half moulds are then placed together; they may be bolted or screwed together (Step 5). Finally the mould is placed in a box surrounded by metal shot, ready to receive the molten charge. Upon solidification of the casting, the mould is separated.



Step 1

Step 2

Step 3

Step 4

Step 5

Step 6

Fig. 2.25: *The steps involved in shell moulding*

Shell moulding offers closer tolerances than die casting and better surface finish than sand casting. It does, however, cost more than sand casting, as to get high dimensional accuracy, the metal pattern plates are expensive to make.

Centrifugal Casting

This method relies on centrifugal force to spin the metal to the outsides of the mould to create a hollow cylinder. This type of casting is useful in creating pipes. Piston rings for cars can be made this way, with a cylinder produced and the rings then cut off the cylinder.

Permanent Mould Casting (die-casting)

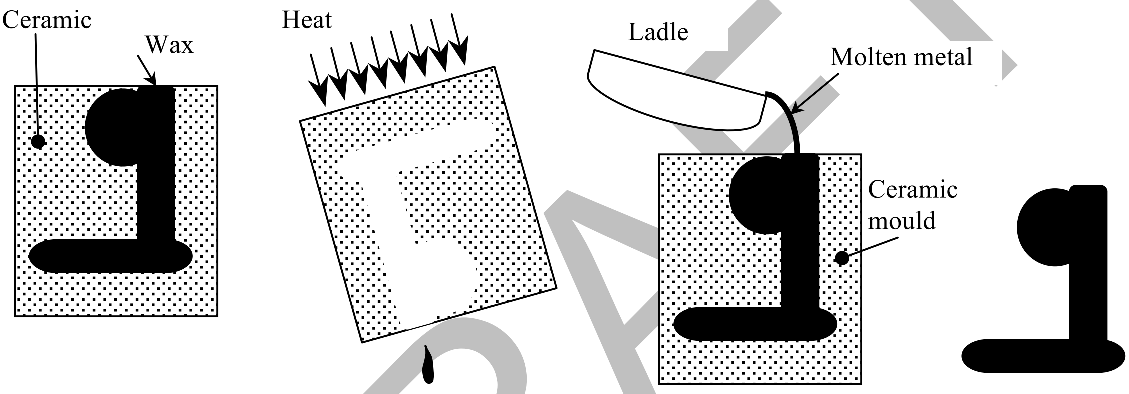
Unlike sand casting, this method involves the use of a permanent mould which is not re-made each time.
(i) Gravity die-casting involves the use of a permanent metal mould, into which molten metal is poured by gravity. Since the mould cannot be broken to remove the cast item, the mould must be able to be separated. The advantages of gravity die-casting on long production runs are that the cost is less than sand casting, and the final casting has a better surface finish. For smaller production runs, however, the permanent steel moulds are too expensive. Many automotive parts, such as pistons, are made using this method.

(ii) Pressure die-casting is a very similar to gravity die-casting, but in pressure die-casting the molten metal is forced in under pressure. The result is a denser casting than is achieved with gravity die-casting. Like gravity die-casting, there is a good surface finish and for high production runs it is quite cost effective. Pressure die-casting is primarily used with lower melting point alloys, such as aluminium alloys and zinc alloys, as dies for high temperature ferrous alloys are expensive. If ferrous

alloys are to be cast using this method, it is necessary to use graphite dies. Gearbox casings may be made using this process.

Investment Casting

Also known as lost-wax casting, this method of casting has existed for centuries. Today it is used in the manufacture of high quality castings where dimensional accuracy and high surface finish are required. Fig. 2.26 outlines the process. A pattern of the item is made from wax and a refractory ceramic is then poured over the material and allowed to set (Step 1). The wax is drained out by heating the mould, leaving a cavity that is the perfect replica of the item to be cast (Step 2). This method will also not leave a line around the casting as the mould is not separable like a die cast mould. Molten metal is poured in and allowed to solidify (Step 3), and then the mould is broken away from the cast article (Step 4). Since the mould is destroyed, a new one must be made each time, so for large runs it can be costly. The final result, however, is worth it, as the final casting has good surface finish and is dimensionally accurate.



Step 1 Step 2 Step 3 Step 4

Fig. 2.26: *The investment casting process.*

There are automated types of investment casting used to manufacture rocker arms for automotive engines. It has found extensive use in transport devices Not only are car rocker arms made this way, but turbine blades for jet aircraft are investment cast and drop outs for bicycles may also be made this way. Investment casting is also used to cast metal alloys that are very hard and difficult to machine as there is little need for machining to size, using this method.

The Full-Mould Process

The full-mould process is a close relative to investment casting, but is usually used for one-off items or prototypes. An expendable pattern for the item to be cast, complete with runner, is made from expanded polystyrene (foam). This is then placed in a box and surrounded by sand with small amounts of thermosetting resin. The molten metal is then poured into the foam runner and this melts the foam. Since only 2% of the foam is solid then this solid simply melts to the sand and helps bind it together. The air, that made up the other 98% of the foam, passes through the sand and does not contaminate the casting.

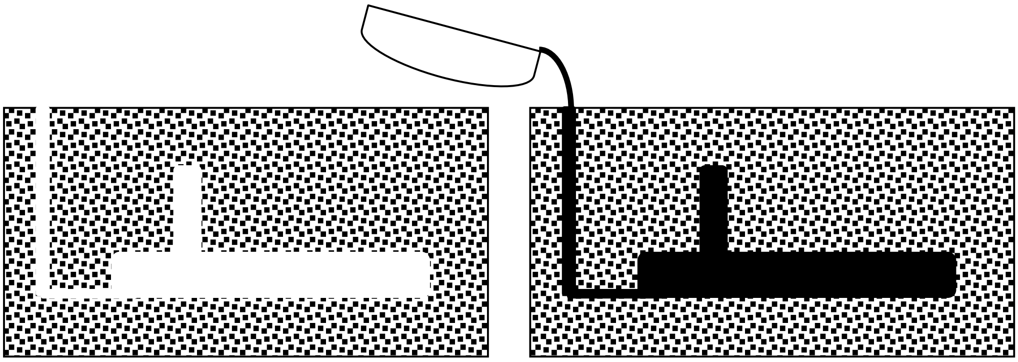


Fig. 2.27: *The diagram on the left is the sand with the foam pattern in place, while on the right the molten metal is poured into the cavity dissolving the foam and leaving the casting behind.*

The full-mould method can be useful in engineering to make a prototype in metal. Suspension systems, for example, may be made like this to assess their design, prior to deciding to mass-produce them, using sand or die-casting.

Extrusion

Direct and Indirect Extrusion

Extrusion may best be likened to squeezing toothpaste from a tube. When the toothpaste comes from the tube it takes the shape of the "die" or nozzle at the end of the tube. The principle is the same with metal. The metal is forced through a die so it takes the shape of the die through which it passes.

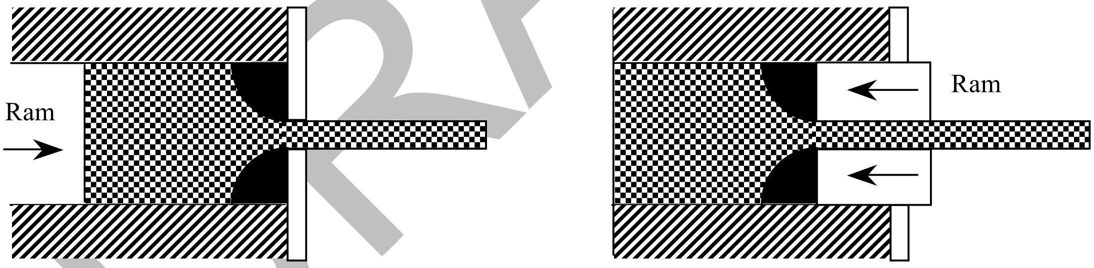


Fig. 2.28: *Direct extrusion is shown to the left and to the right is indirect extrusion.*

Extrusion comes in two forms; direct, where the ram pushes the metal into the die from the other side, and indirect, where the ram and die are the one part. Both are shown in Fig. 2.28. Direct extrusion generally requires more effort so it is used with more ductile materials. Indirect extrusion is used in the extrusion of alloys with lower ductility, but, because the equipment required is more expensive, direct extrusion is used where possible. Both direct and indirect extrusion are hot working processes.

Tubing may be made through extrusion by a mandrel placed in the centre of the die to create a hollow section.

Impact Extrusion

Unlike the other types of extrusion, this is a cold forming process. Impact extrusion involves the use of a hammer impact to extrude a shape. The punch goes into a die and the material blank is forced from the die around the punch. Cans and short tubes are often made using this method.

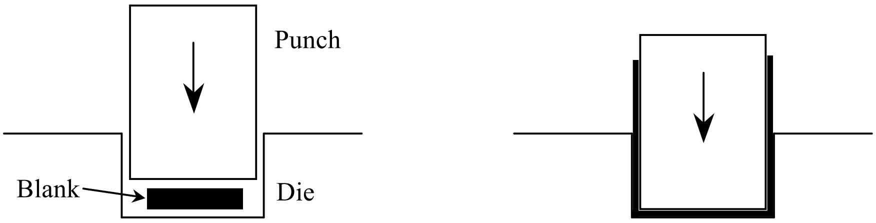


Fig. 2.29: *In impact extrusion, the punch forces the metal to flow out of the die and around the punch.*

Powder Forming

Metal powder forming or powder metallurgy is a process that finds extensive use. The process involves first getting the metal into powder form. This may be done by mechanical disintegration such as grinding, atomizing the metal from liquid form by chemical means, or by electrolytic methods.

Once in powder form, the powders are blended with stearate based dry lubricants, to get the required mix. They are then pressed into a mould to form the shape required. The pressure used is enough to compact the particles together and give the item sufficient strength to be handled. Once pressed, the item is sintered, in a non-oxidising controlled atmosphere furnace, at a temperature to allow atoms to diffuse between grains, producing a homogeneous grain structure (Fig. 2.30). This gives the product its final strength.

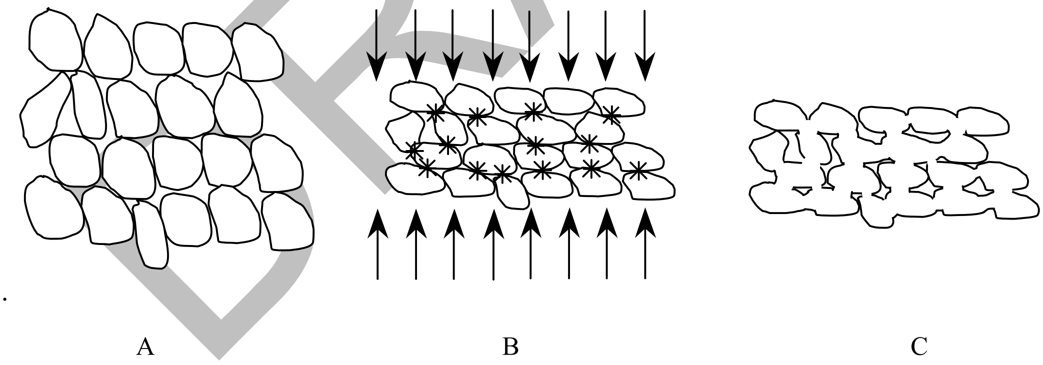


Fig. 2.30: *The steps in powder forming, A shows the powder particles in a free state, B shows them cold welding because of the pressing, and C displays the structure after sintering. Note the grain growth where the cold welding was.*

Products of Powder Forming

The products of powder forming can be grouped into four general groups: porous metals, complex articles, products difficult to machine and composites.

Porous metals are produced by deliberately using larger powder sizes, the result is metal products with porous properties. Such metals can then be impregnated with oil of polyterafluroethylene (Teflon) to give a lubricating effect. Such self-lubricating bearings are used in bicycle suspensions and electric motor bearings.

Complex articles are another. Some shapes are simply too difficult or too costly to cast and machine so they are powder-formed instead.

Products difficult to machine are those articles made of materials that are too hard to machine. Metals like tungsten cemented carbides are difficult or nearly impossible to machine so powder forming may be used.

Composites can be readily formed. Many materials will not combine to form an alloy but can be formed together as powders to capitalize on their individual properties. Materials such as copper or silver may be mixed with tungsten or nickel for electric contacts. These will not alloy together so powder forming is used. The copper provides good electrical conductivity while the tungsten provides resistance to oxidation and wear.

Advantages and Disadvantages

Powder forming allows many articles to be produced that otherwise would be difficult to make. Sintered components are used in automotive gearboxes and perform better than manufactured parts. It is, however, expensive to set up powder-forming facilities and the shapes are still somewhat limited. The finished article is also not as strong as a conventionally produced item.

Welding

Welding processes are summarised in Table 2.2

Non-Ferrous Metals and Alloys

There are a huge variety of non-ferrous metals and alloys, yet they are still not used as extensively as the various ferrous alloys. They have, however, carved out a substantial niche for themselves, offering diverse properties that the ferrous alloys find hard to match. While the range of non-ferrous metals and alloys is broad, this section is mainly concerned with the ferrous alloys of aluminium and copper.

Aluminium and its Alloys

There is a wide range of aluminium alloys used in transportation systems. They have become more widely used since WWII as a solution to reducing weight in bicycles and cars.

Aluminium

Aluminium is one of the most common metals in the Earth's crust. It was not, however, until the 20th century that it was no longer a precious metal. In nature, aluminium exists as the ore, bauxite and because of its reactivity in elemental form it is never found in nature as pure aluminium. So it was not until a satisfactory method for refining the ore was developed by Hall and Heroult in 1886, that it became an affordable metal.

Table 2.2: Summary of welding processes.

	Welding method	**Type of process**	**Method**
1	Spot welding	Pressure	Electric current melts metal sheets under pressure joining it in “spots”. This process is extensively used in the manufacture of cars and is how most car body panels are joined at their seams
2	Butt welding	Pressure	Metal is butted together at the ends and current melts the metal joining it together. Useful for joining tubes end on.
3	Seam welding	Pressure	Metal is moved through rotating wheels that pass electric current into the metal, melting it, then joining it. Seam welding is used in the manufacture of tubes for cheap bicycles. The flat steel is rolled into a tube and welded at the seam. High quality tubes are however, seamless.
4	Oxy-acetylene welding	Fusion	Metal is melted by oxy-acetylene flame and a filler metal is added. This process is extensively used in repairs and finds greater use in home style DIY projects than in automated manufacture now.
5	Bronze welding	Fusion/ alloying	A flame (usually oxy-acetylene) heats the parent metal and bronze filler metal is added to the joint. Unlike oxy-acetylene welding there is little or no melting of the parent metal. The process resembles brazing except the filler metal is built up at the joint. This process works well for lower temperature projects that cannot have the parent metal melted.
6	Electric arc welding	Fusion	Metal is melted by an electrode, which is also the filler metal, because as the arc is struck the electrode melts into the joint. The temperature of the arc is over 3000°C at the tip. The electrode is covered in a flux to prevent oxidation of the weld metal. Because the electrode is consumable it must be changed periodically, and as it is used the welder must move his/her hand down to maintain the arc
7	Metal inert gas (MIG) welding	Fusion	MIG (Metal Inert Gas) replaces the electrode with a continuous feed wire thus facilitating quicker welding. The flux is replaced by an inert gas which may either be argon or Argoshield, (a mix of argon and carbon dioxide) that protects the weld metal from oxidation when molten. This process is well-suited to automation and is used extensively in many manufacturing industries, such as bicycles and cars.
8	Tungsten inert gas (TIG) welding	Fusion	Similar to MIG, TIG (Tungsten Inert Gas) replaces the continuous feed wire with a tungsten electrode and a filler rod fed by the operator. Like MIG an argon shiled is use to protect the weld from oxidation. It is like combining the methods of oxy-acetylene an electric arc. This process is the chosen method for welding materials like stainless steel, aluminium alloys and titanium alloys.
9	Plasma arc welding	Fusion	A gas, such as argon, is passed through an electric arc. The gas ionises electrons and positive ions. This mixture is called plasma. The ions recombine and form a hot flame. It is used with refractory metals such as tungsten and molybdenum.

Aluminium is extremely reactive, has relatively low strength, is ductile, has low specific gravity and is easily fabricated. It is more difficult to weld than ferrous alloys and it is also more costly than mild steel.

What aluminium does offer, is a good strength to weight ratio, corrosion resistance, due to the formation of a tenacious oxide film and good electrical conductivity, only surpassed by gold, copper and silver. In fact, when comparing weight to conductivity, aluminium is a better conductor than copper.

Aluminium is used for overhead electrical wiring, in the manufacture of cooking pots and pans, and for cooking foil. Because of its low strength, most engineering applications are for aluminium alloys.

Aluminium Alloys

Aluminium alloys fall into the loose categories of wrought and casting alloys. The casting alloys are used exclusively for casting while the wrought alloys are for mechanical working.

Wrought alloys: Beyond this classification there are heat treatable and non-heat treatable alloys.

Summary

N.B. For aluminium alloys, the numbering system is such that the first number relates to the family of alloys. The remaining three numbers, shown as xxx for our purposes, describe the varying composition of alloying elements within the families.

Non-heat treatable alloys

1xxx Primarily pure aluminium with small amounts of iron and silicon. Used mainly for sheet metal work.

3xxx Manganese is primary alloying element, provides solid solution strengthening. Used for pressure vessels, chemical equipment and sheet metal work.

5xxx Magnesium is added as the primary alloying element. 5052 (approx. 2.5%Mg, 0.2%Cr) is the most important industrial alloy in this family. Used for sheet metal work, particularly for truck and marine applications.

Heat treatable alloys

2xxx Primary alloying element is copper. Family includes duralumin (2017 – 4 % Cu), which is a well-known alloy, strengthened by solid solution strengthening and precipitation hardening. Primarily for aircraft structures because of high tensile strengths (approx. 4 times that of mild steel).

6xxx In this series there are two primary alloying elements, magnesium and silicon, strengthened by precipitation hardening, good corrosion resistance and strength, used in bicycles frames, truck and marine structures.

7xxx This series, primary alloying element is zinc, but many alloys such as 7075 have additions of magnesium and copper. Alloy strengthened through precipitation hardening. Alloy elements allow denser precipitates; produce a stronger alloy, strengths up to 500 MPa, used in aircraft structures and good quality bike frames.

Casting alloys

Like the wrought alloys the casting alloys are broken up into non-heat treatable and heat treatable. Most aluminium alloys are cast, using either sand casting, gravity die-casting or pressure die-casting. Most of the casting alloys contain silicon, in the range of 5 to 12%, as this tends to produce a lower melting point for the alloy and improves the fluidity of the molten alloy. It also tends to strengthen the alloy. Manganese and copper may also be added to improve strength and hardening qualities.

An important aluminium-casting alloy, used in the transport industry, is the aluminium/silicon/magnesium/iron alloy. This is used in the manufacture of alloy wheels in cars.

Like aluminium wrought alloys, casting alloys use a numbering system, where the primary alloying element decides the number that is allocated. Table 2.3 lists them below.

Table 2.3: *The aluminium casting alloy designations*

Major Alloying element plus additions	Number
Aluminium, (99% or greater)	1xx.x
Copper	2xx.x
Silicon with Cu and/or Mg	3xx.x
Silicon	4xx.x
Magnesium	5xx.x
Zinc	7xx.x
Tin	8xx.x
Other elements	9xx.x

Aluminium Lithium Alloys

This alloy deserves mention, because of its use in the manufacture of bicycles. Aluminium lithium alloys create bicycle frames that offers a 100% better fatigue life and 50-100% better strength than 6061 aluminium alloy tubing. Such an alloy is important in the competitive world of cycling. This alloy was first used in the advanced aviation fields.

Copper, Brass and Bronze

Copper and its two alloys, brass and bronze are immensely important to the engineering world. Bronze, amazingly, has been used by humanity since 3,000 BCE, so when you use a bronze item you have something in common with the ancient Egyptians or Mesopotamians.

Copper

Prior to the Bronze Age, copper was by far the most important metal. Nowadays it is the third most used metal. The "big three" metals are iron, aluminium and copper. Copper finds extensive use in the electrical industries, as its conductivity is second only to silver. It is, however, far more cost effective as a conductor than silver and finds extensive use in railway overhead wiring.

Brass

Brass is an alloy of copper and zinc. The relative amounts of these materials have a large impact on structure and properties. Commercial brasses rarely contain more than 40% zinc as beyond this level of additive, the alloy becomes brittle and is of little use. A list of common brasses is shown below

Cartridge brass also known as 70/30 brass contains 30 % zinc. The alloy is quite ductile and was formerly used in the manufacture of cartridges for bullets, hence the name. The alloy has higher ductility than the copper from which it is mainly composed, which makes it perfect for deep drawing operations.

Standard brass has only 25% zinc and is a good quality, cold working alloy used where the ductility of cartridge brass is not required. It is used for stampings and limited deep drawing.

Muntz Metal, a two phase brass, contains 40% zinc and because of the formation of a brittle phase in its microstructure it is usually hot-worked to shape. It is used in the manufacture of rods and bars. It may also be cast. Tap bodies, for example, are cast using this alloy. Muntz metal can be heat-treated to change its properties.

Naval Brass contains 37% zinc and 1% tin, with the tin adding to the corrosion resistance in seawater, an important consideration in shipbuilding.

High Tensile Brass, also called manganese bronze, is a copper (58%) zinc (≈36%) alloy with small additions (<1.5%) of manganese, aluminium, lead iron and tin. These improve the tensile strength over other brasses, at the expense of ductility. It is used for stampings and pressings, but also for marine propellers and rudders.

Tin Bronzes

The term bronze relates to the tin bronzes as opposed to aluminium bronze outlined further on. In fact, the term bronze is often used to describe copper alloys but the original meaning is a copper/tin alloy. Tin bronzes usually contain tin within the range of 3 to 18 %. A list of common tin bronzes and gunmetals are listed below.

Low tin bronze, with only 3.75% tin is aptly named. It demonstrates good elastic properties and corrosion resistance. It is used for springs.

High tin bronze, with large amounts of tin (18%), is used in heavy load applications, such as slewing turntables on large cranes

Admiralty gunmetal, is a bronze with 88% copper, 10% tin and 2% zinc and some nickel. The zinc makes the alloy more fluid in the liquid state, which suits casting. It is used for pumps, valves and especially marine castings, as it has good corrosion resistance in salt water.

Leaded gunmetal, or red brass, has 85% copper and 5% tin, but also 5% zinc and 5% lead, which reduces ductility and makes it more suitable than Admiralty gunmetal for pressure vessels.

Phosphor bronzes are, bronzes with deliberate amounts of phosphorous added as opposed to trace amounts left over from refining. They tend to have higher tensile strength and corrosion resistance than standard tin bronzes. Importantly, they also have a lower coefficient of friction, that makes them suitable for bearing applications.

Aluminium Bronze

This is a copper alloy with the primary alloying element being aluminium in amounts up to 11%. Aluminium bronzes offer good corrosion resistance, and good tensile strength. Their corrosion resistance sees them used in marine and chemical applications. Casting them is difficult because of the oxidation of the aluminium, so great care must be taken when pouring the molten metal. Aluminium bronze is hardenable through heat treatment, outlined further on.

Structure/Property Relationships

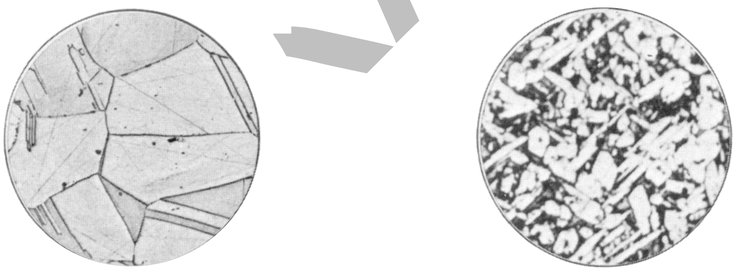


Fig 2.31: *Microstructures for cartridge brass (left) and Muntz metal. [Reproduced with permission from Gibson, J. & Taylor, T. (1979)* Experimental Materials Science.*]*

The microstructure has a large impact on the properties of many non-ferrous alloys. In many cases a second harder phase is often present which reduces ductility, e.g. Muntz metal. The microstructures for Cartridge Brass and Muntz metal are shown above. Fig. 2.29. The white phase, which is not pure copper, is ductile, whilst the dark phase contributes to the brittleness of the alloy.

Heat Treatment of Non – Ferrous Alloys

Annealing is done to relieve internal stress. Annealing, as for ferrous alloys, is done to remove stress that may result from cold working the alloy when producing sheet, plate or bar metals. Each alloy will have an optimum annealing temperature. The result is an equiaxed grain structure similar to that shown in Fig. 2.33 B.

Precipitation hardening is done on duralumin (Al/4%Cu) and other aluminium alloys. The aluminium alloy will, after casting or being hot worked, present as an alloy with a primary phase (α) and a secondary phase (β) usually at the grain boundaries, Fig. 2.32 (A). Two steps follow:

Step 1 – Solution Treatment: The alloy is heated to 530°C until the β phase dissolves to produce a homogenous single phase alloy. The alloy is then quenched to room temperature. The resulting structure will be a single phase microstructure of equiaxed grains of α (Fig. 2.32 B)
Step 2 – Aging: Over time the trapped β phase precipitates out on stress planes within the quenched phase, thus restricting dislocations and strengthening the alloy. This β precipitate is very finely dispersed through the structure (Fig 2.32 C). This process is called *natural aging.* It is possible to accelerate precipitation by reheating the alloy to about 150°C; this is known as *artificial aging*. This must be done carefully because if artificial ageing is done for too long that alloy can be over aged and becomes brittle.

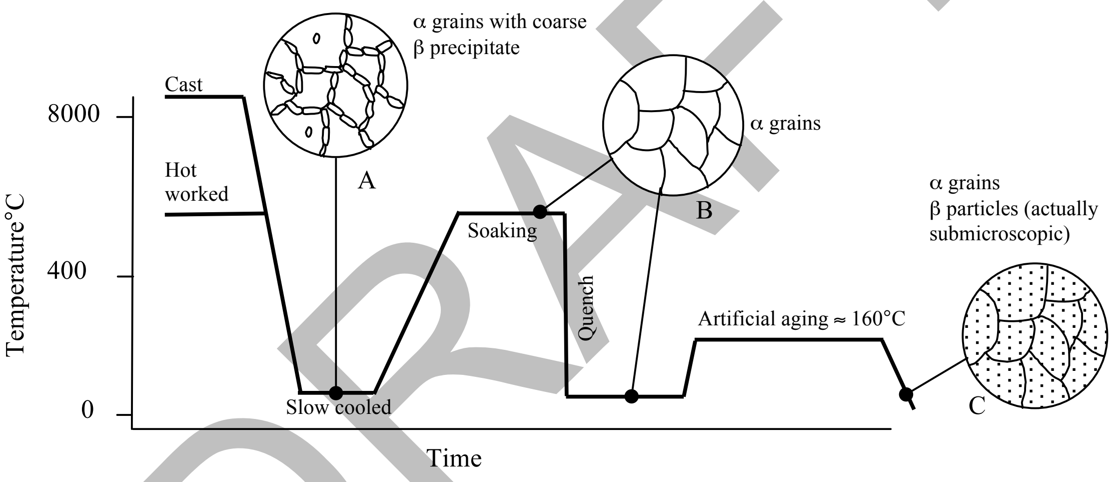


Fig. 2.32: *The precipitation hardening (age hardening) process for duralumin. After slow cooling the alloy is reheated, soaked and quenched. Then in this case it is artificially aged.*

Aluminium bronze (Cu/11%Al) may also be heat-treated. When quenched, it forms a hard structure that is similar to martensite in steels; hence it is named *β Martensite*. It can be tempered in a similar manner to steels forming a tough product.

Ceramics and Glasses

Ceramics

Ceramics offer a range of properties that make them desirable for transport applications.. Research has been conducted into manufacturing petrol and diesel motors from ceramic materials to improve thermal efficiency. Since ceramics can withstand higher temperatures than metal alloys used in engines they could, conceivably, run at higher operating temperatures, without cooling systems. As a cooling system is responsible for the loss of around 20% of the heat energy the motor uses, improved thermal efficiency and better fuel efficiency would be the results of a ceramic motor. Unfortunately these motors have never progressed beyond the experimental phase. Modern ceramics, such as partially stabilized Alumina and Zirconia, do not possess the brittleness normally associated with ceramics such as porcelain and china. They are also strong enough to withstand the forces and shock waves developed in an internal combustion engine. Ceramics are now used for high performance disc brakes because of their improved performance at the elevated temperatures which high performance car brakes experience.

While ceramic materials may not initially be thought to be important to transport systems but they have their place. For example, the humble spark plug relies on an alumina insulator for operation. The alumina offers insulation, thermal stability and resistance to vibration, properties hard to find away from ceramics.

Glass

Apart from cycling, all forms of transport rely on glass in one of its many forms. Glass may be defined as an inorganic fusion product that has failed to crystallise upon cooling. Glasses are generally not crystalline but amorphous (except for glass-ceramic, Volume 1 p28). The structure of glass does not allow for deformation. So, when glass is deformed, it is unable to dissipate the applied forces through a slip/dislocation mechanism. Once the bond resistance is exceeded, the structure fractures. The speed of fracture is very rapid. There are four general categories of glass used. These are listed below.

High Silica Glass is refined from borosilicate glass and is nearly entirely silica (SiO_2). These glasses are almost perfectly clear, and are used in situations where they experience elevated temperatures, such as in missile nose cones and space vehicle windows.

Soda Lime Glass is the most common glass. It contains large amounts of soda (Na_2O) and lime (CaO). The presence of soda will prevent devitrification (crystallisation), however, it also makes the glass water-soluble. The addition of lime alleviates this, hence the name Soda Lime Glass. Soda Lime Glasses soften at approximately 850°C, are easily formed to shape when hot, will not recrystallise, are water resistant, and cost effective. It is used for window and plate glass, bottles, tableware, electric light bulbs and windscreens.

Borosilicate Glasses are glasses with up to 20% boron and silica. This imparts good levels of chemical resistance and low thermal expansion, so these glasses have high resistance to fracture at elevated temperatures. Borosilicate glasses, one of which is known by the trade name "Pyrex", are extensively used in electrical insulation, gauge glasses for laboratory ware, and domestic cooking and ovenware.

Lead Glasses contain up to 40% lead. This lowers the softening temperature to well below the 850°C of soda lime glass. They have a high refractive index, which makes them optically clearer. They are used extensively for optical glass. They are also used for thermometer tubes and the tableware known as "crystal" which is a misleading name as they are not crystalline.

Ceramics as an Insulating Material

In terms of transport one of the best examples of a ceramics as an insulating material is in spark plugs. Spark plugs carry large voltages, but also are subjected to high temperatures caused by combustion; this makes polymers unsuitable as the insulator. So alumina is used as an insulator between the threaded metal body and the inner copper electrode. This stops the spark being earthed by the contact between the spark plug's metal thread and the engine block.

Ceramic insulators are also used in supporting power lines, such as the overhead wires for electric trains. Here glazed porcelain is used, although glasses have been used as well at times. A newer development in porcelain insulators has been mildly conductive glazes which use a small milliamp flow of electricity on the surface of the insulator to prevent contamination by dirt and dust, which minimises the chances of arcing.

Laminating and Heat Treatment of Glass

Glass is rarely used in its normal condition in transport devices. Normal glass is far too brittle to resist projectiles. As a consequence two processes, that strengthen glass, are used. Laminated and toughened glasses are outlined in Chapter 1 pages 58 and 54 respectively.

Polymers

Structure/Property Relationships and Applications

Thermoplastics (or thermosoftening polymers)

This type of polymer softens on the application of heat. It can also be re-melted and reformed. Thermoplastics have long linear chain structures, with the chains formed by covalent bonds. Weak van der Waal's forces hold the separate chains together. As a consequence, they are usually flexible and often transparent. When put under a tensile load, they stretch readily, as there is little resistance to the chains straightening or sliding over one another (refer to Volume 1, p 26). Examples are polyethylene, polystyrene, polytetrafluroethylene (PTFE), polymethylmethacrylate (acrylic), polypropylene, polyvinyl chloride (PVC) and acrylonitrile butadiene styrene (ABS). They find use in cable coating on bicycles and for car parts such as grilles, badges, door handles and window winders.

Thermosets (or thermosetting polymers)

This type of polymer undergoes a chemical change when heat is applied. The change is not reversible so these polymers do not soften when they are reheated. Thermoplastics have network structures, with covalent bonds, along the chains and across the chains. They tend to be more rigid than thermosoftening polymers. When they are put under tension, the cross-linking resists deformation. This makes them less flexible than a linear polymer. Epoxy resins, silicone, polyurethane and polyester resins are examples of thermosetting polymers. Epoxy resins find use in the aircraft industry for joining panels, and the silicones are often used in gasket manufacture for cars. Epoxy resisn also find extensive use in bicycles and racing cars for use as the matrix in carbon fibre reinforced polymers.

Rubber

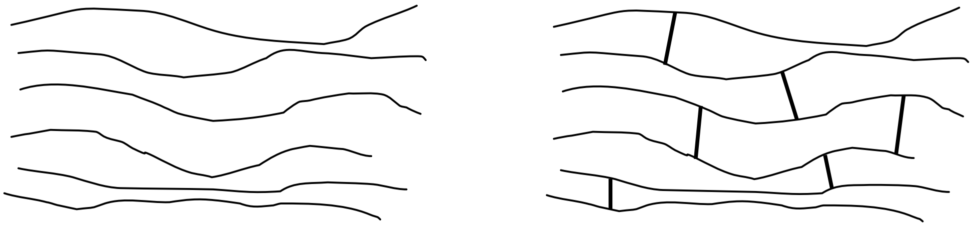


Fig 2.33: *Raw rubber, on the left, has polymer chains that have no linking. The vulcanised rubber structure, on the right, has cross-linking to improve rigidity.*

Rubber is a natural polymer. In synthetic form it has great use in transport. The tyres for cycles and cars use a modified rubber, which is called *vulcanised rubber*. Rubber in its natural form is a linear polymer that is too flexible for use in a tyre. By adding around 5% sulphur to the rubber mix and heating it to about 150°C, a moderate level of cross-linking is achieved. The vulcanised rubber is more rigid, but still flexible. To increase rigidity, tyres are usually constructed from a composite of rubber with cotton strands, while radial tyres for cars use steel wire and polyester cord.

Engineering Textiles

Engineering textiles are polymer resins that are drawn into threads and then woven into 'cloth' like sheets. They are an important field in the world of engineering. The engineering textiles are synthetic polymers and offer vast improvements over natural fibres. Various engineering textiles that are used today are discussed below.

Polyester is a synthetic fibre that is strong and resilient. It is also hydrophobic, i.e. resistant to water absorption. It is used in helium airships, and in the manufacture of some tyres. It is also used in the manufacture of various car parts, like fan belts and radiator hoses.

Nylon finds use in the engineering world in dry lubrication. It is now being replaced by PTFE (polytetrafluroethylene). It is resistant to acids, bases and oil.

Aramid fibres are extensively used in engineering. Nomex™ and Kevlar™ are the best known examples. These aromatic polyamid polymers are strengthened by a backbone of benzene rings. They have excellent strength qualities but are limited to low temperature uses. They are used in aircraft manufacture and in bullet-proof vests.

Olefins are polyethylene or polypropylene fibres shaped into sheets. They are waterproof and find use in the manufacture of collapsible shelters and buildings.

PTFE (Teflon) fibres are fire resistant and will also stop water vapour, but not water. They are used for filters in engines.

Manufacturing Process For Polymer Components

Blow moulding

This is used to shape thermoplastics. A polymer tube is lowered into a mould, and air forces the tube to the shape of the mould. It is used to make plastic bottles and containers.

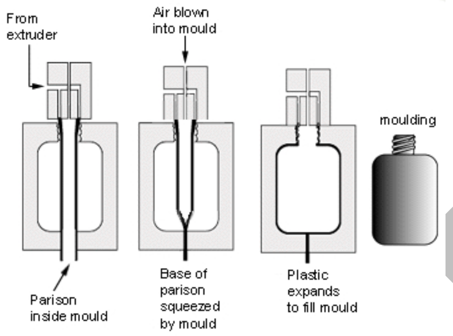


Fig 2.34: *Blow moulding (from http://tinyurl.com/blowmoulding)*

Extrusion

As for metals, polymers can be extruded, with the polymer taking the shape of the die through which it is extruded. The polymer granules are melted and the molten material is forced through the die. This process is only suitable for thermosoftening polymers. Polymer tubing is manufactured using this method. The outer covering of bicycle cables is coated with plastic in this way.

Thermoforming

This process is used in the manufacture of various thermoplastic containers. Heated thermoplastic sheets are placed over dies to produce the required shape. The forming can be done using matching dies, a vacuum or air pressure. Often, special thermoplastic sheets are used for this process.

Calendaring

A thermoplastic is poured into a cavity between two rollers, and the plastic is squeezed through the rollers. The rollers may be embossed with patterns or they may be smooth. Tiles, films and curtains can be made this way.

Rotational moulding

The molten polymer is poured into a mould and the centrifugal force throws the polymer to the walls of the mould, forming a hollow article.

Injection Moulding

This is one of the most commonly used polymer forming procedures. Molten polymer is injected into a cavity in the shape of the finished article. When the polymer solidifies, it is ejected and the procedure starts again. Injection moulding lends itself readily to mass production. Many items are injection moulded and are often identified by a small nipple on the item and a split line where the polymer was injected into the mould. They are used in the manufacture of small thermoplastic mouldings for cars and bicycles.

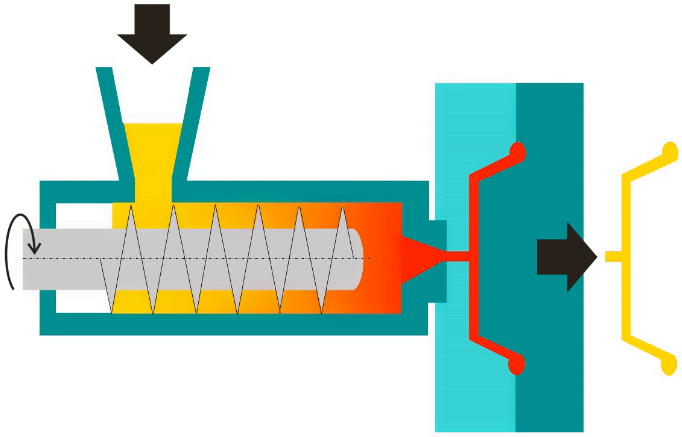


Fig. 2.35: Diagram representing the injection moulding process.

It is strongly suggested that students refer to *Additional Resources* section to find information on plastics forming. The books by D. Askeland and W. Smith have excellent coverage and diagrams of plastics forming.

Engineering Electricity/Electronics

Power Generation/Distribution

Generation

In Australia electricity is produced in a number of ways. Some are listed below.

Coal burning power stations are by far the most common method of electricity generation. Here coal is used to produce steam that drives a steam turbine. The turbine connects to a generator that is spun, producing electricity. Because coal is a readily available resource this method is very popular in Australia. Unfortunately, this produces huge volumes of carbon dioxide, which contributes to the greenhouse effect.

Hydroelectric systems offer electricity without atmospheric pollution. They utilise water held in dams above the power station. The waters potential energy is converted to kinetic energy as it travels through pipes to the power station. At the power station, the water drives a turbine connected to a generator. This produces electricity, and the water is fed back into water systems for irrigation. While this system sounds totally "clean", it has large impacts on the surrounding environment because of the damming and diverting of rivers. It is also only possible in mountainous regions. One unforeseen side-effect of the Snowy Mountains hydroelectric scheme has been rising salinity levels because of irrigation and farming in formerly dry regions.

Wind power is often touted as a solution to power demands. The wind drives a large turbine with blades far more efficient than the ancient windmills. The turbine drives a generator and produces electricity. While it is truly clean, to power larger towns and cities, a very large number of turbines are needed, so large tracts of land must be devoted to it. Wind, in many places, is intermittent and unreliable, which also limits this method. Wind “farms” exist in Perth (WA), in Goulburn (NSW) and in New Zealand.

Nuclear Power – a loaded gun or not?

One very contentious issue in Australia is nuclear power. In the recent Kyoto summit on global warning, nuclear fission power emerged as a method that does not contribute to global warming. The benefits of nuclear power are great. They operate like coal power stations, but instead of the water being turned to steam by coal powered boilers, the heat from the nuclear reaction is used. Only a small amount of nuclear fuel is required to produce large amounts of heat. It is non-polluting to the atmosphere but it presents other problems. The by-products of nuclear power generation are often contaminated for thousands of years, and there have been two accidents (Three Mile Island and Chernobyl), that occurred because of human error, proving that all the failsafe systems are still vulnerable.

Until it is proven that nuclear fission is completely safe, it will remain contentious in Australia.

Distribution

In recent years many smaller power stations have been closed and replaced by larger ones in more remote locations. For example, in the Sydney and Wollongong areas, there are now no power stations. These areas are fed by the larger power stations of Eraring and Vales Point near Lake Macquarie, Mt Piper near Newcastle, Wallerawang in the Lithgow area, Bayswater and Liddell in the Hunter Valley and the Snowy Mountains Hydroelectric system. This means that the distribution and carriage of electrical energy becomes very important.

The power lines used to carry electricity are steel cored aluminium. The steel core provides the strength to let the wire support itself, and the aluminium provides the electrical conductivity. There are now cables being made that replace the steel core with a carbon and glass fibre reinforced polymer composite. Although aluminium has only 60% of the conductivity of copper, its vastly lower density means that per kilogram, aluminium is a better conductor. When copper conductors are used, as in the railway system, more poles are required because of its extra weight.

To reduce resistive loss in aluminium cable, power is transmitted along transmission lines at very high voltages, i.e. 333,000 volts and even 500,000 volts. Power loss is directly proportional to the voltage, and the current squared. Raising the voltage reduces the current for the same amount of power, thus reducing the resistive loss in the cable.

In addition to the power lines, various substations are used to reduce the high voltage to the 240 volts that is then fed to urban areas.

AC/DC Circuits

Alternating Current (AC) and Direct Current (DC) differ considerably. DC has a constant potential. AC has a constantly varying voltage. In Australia, the AC mains power varies from 0 to +240V, to 0 and –240V, every 1/50th of a second.

It is possible to run a DC appliance on AC but the AC must be "converted" into DC. This is never fully effective but it is good enough to be used practically.

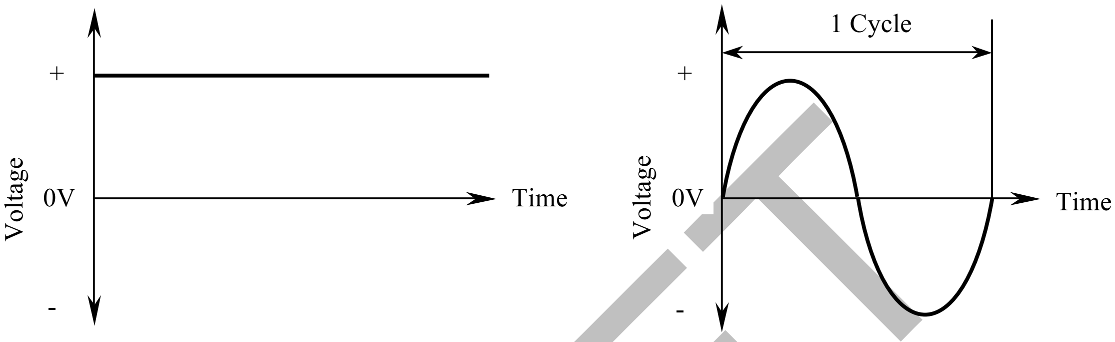


Fig. 2.36: *In (A) DC current maintains a constant potential. In (B) AC voltage flows in the shape of a sine wave.*

Rectification

The conversion of AC to DC is called rectification. Half wave rectification occurs when one diode is used (see p 123 for the operation of a diode). This eliminates the current flowing the opposite way, so blocks the negative part of the waveform.

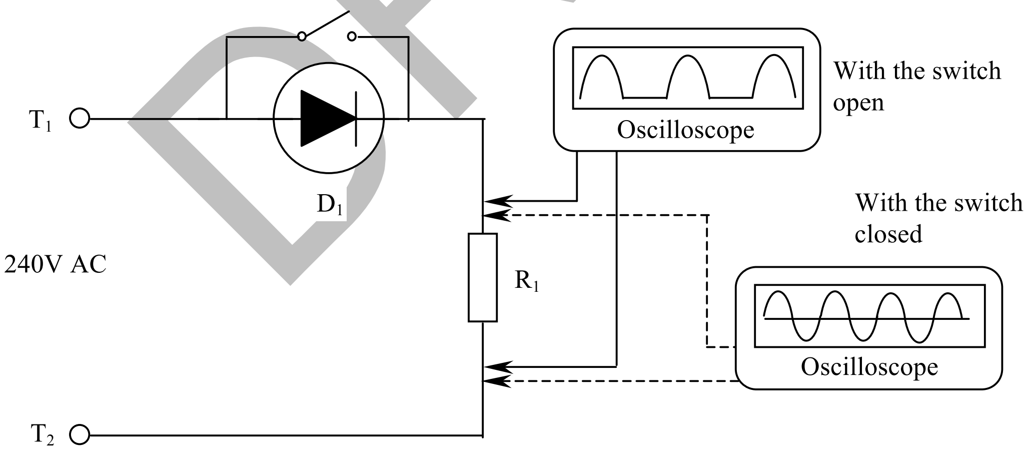


Fig 2.37: *The half wave rectification is gained by a single diode in the AC circuit. The diode will block current in one direction, so only the negative direction is blocked. With the switch closed, AC can flow and the oscilloscope shows an AC waveform.*

Full wave rectification can be achieved by using four diodes. This will allow all of the sine wave to pass but it will have all of the waves on the positive side, so they will travel in the same direction. The final waveform is not true DC, but a varying DC. The four diodes are connected as shown below.

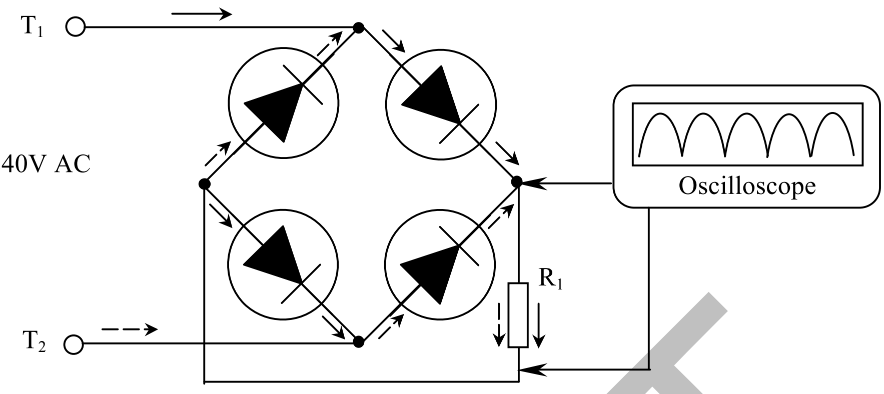


Fig. 2.38: *Full wave rectification is achieved by the four diodes connected as shown.*

This varying DC, produced by both the half and full wave rectifier circuits, is not ideal for most DC equipment. To achieve a better waveform, a capacitor is added to either rectifier circuit. The capacitor stores energy that can be used when the waveform reduces in voltage. The result is a nearly flat waveform, with the capacitor smoothing out the troughs.

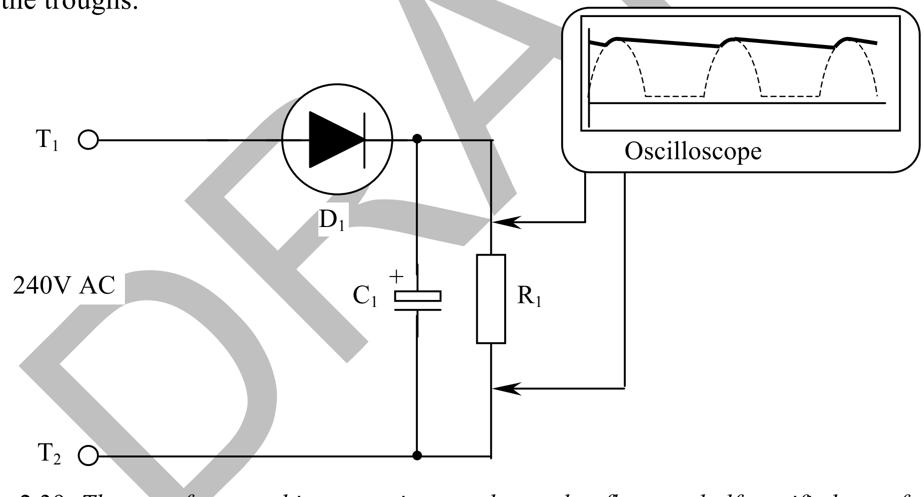


Fig 2.39: *The use of a smoothing capacitor can be used to flatten a half-rectified waveform.*

When T_1 is positive the diode (D_1) passes current and the capacitor (C_1) charges to a potential equal to the AC supply. Current will also be flowing through R_1. When the potential at T_1 falls then the capacitor releases its charge and the circuit uses power stored in the capacitor. There is a slight voltage rise when T_1 becomes positive again, which is minimised by ensuring the capacitor value times the resistor value is larger than the cycle of the AC which is $1/50^{th}$ (0.02) of a second. Stated mathematically,

$$C_1 \times R_1 > 0.02$$

For efficient smoothing of the DC output it is best if the product of the capacitance and the resistance is 5 times the AC cycle time.

Example 2.13

What will be the required capacitor value for an AC (cycle = 0.02 s) rectifier if the resistor used has a value of 390 Ω?

$$C_1R_1 = 5(0.02)$$
$$C_1 = \frac{5(0.02)}{R_1}$$
$$C_1 = \frac{0.1}{390}$$
$$C_1 = 2.56 \times 10^{-4}$$
$$C_1 = 256\ \mu\text{F}$$

Therefore the capacitor required for this rectifier would be 256 μF.

In rectifier circuits the smoothing capacitor is usually an electrolytic capacitor and the value lies in the range from 470 μF to 2200 μF.

Electric Motors used in Transport Systems

Many years ago only DC motors were used in trains, partially because it was difficult to control AC motors when the generator driven by the diesel engine produced DC. Nowadays, however, there are AC induction motors used in diesel electric trains. In NSW older electric trains still run using DC power, while newer electric trains now use AC motors. See Volume 1, pp 77-79 to review how electric motors work.

DC Motors

Shunt wound motors are rarely used in locomotives. They have constant speed but low starting torque and therefore not suitable if there is a lot of stopping and starting.
Series wound motors offer excellent torque at slow speeds and will operate at high speed under light load. This makes them excellent for use in trains, and is a reason why they are widely used.
Compound motors combine the best features of the other two. Good starting torque and will not run away under no-load conditions.

AC Motors

The AC motors used in trains are generally induction motors. Their great advantage is a lack of commutator and brushes, which wear out over time. They rely on the frequency of the electricity and magnetic induction for their power and. Their function is helped by generators being replaced by alternators on diesel electric trains. Alternators produce AC so one would assume the use of an AC motor would be easier.

On the English Channel Tunnel, locomotives are powered by single phase AC voltage, which is rectified to DC voltage, passed through a control circuit. The voltage is the converted into AC for the motors.

The Millennium trains used on the Sydney rail network use 3 phase induction motors, but because the supply is 1500 volts DC the train uses an inverter to create AC from the supply DC voltage. Pulse Width Modulation (PWM) is used to control the motors.

This large field can be further researched through the Additional References section at the end of the chapter. The author also recommends this website for electric motors:
http://www.phys.unsw.edu.au/hsc/hsc/electric_motors.html

Pulse Width Modulation

Pulse Width Modulation (PWM) is a method of controlling electric motors in an electronic manner. Instead of varying the voltage or current levels in an analogue way, the supply is effectively switched on and off rapidly to replicate an average on time equal to a set level, e.g. 50% power created by being off and on 50% each. To understand this process imagine a standard light, and that it can be switched on and off at a rate faster than the human eye can detect. Now imagine that the light is off 50% of the time and on 50% of the time, the resultant effect will be the lights seem to be dimmed by 50%. Or furthermore if we adjust the off to on time to be 75%-25% then the lights will appear to be 25% of full light.

Control Technology

Control technology is the use of some type of mechanism or circuit to control the operation of an item. The simple float arm in a toilet controls the water delivery; this is an example of control technology.

In transport, one of the earliest control devices was the governor on steam engines. Centrifugal force caused arms to rise. This controlled a throttle system, which more-or-less maintained the engine at a constant speed under varying loads.

Cars often have electronic cut-outs that sense the speed of the crankshaft and cut the ignition to the car if the engine revs too fast. Control technology has been trialled for years on car suspension, trying to reduce the compromise by engineers between ride and handling, that exists with conventional suspension systems.

Control technology can be a simple mechanical linkage, a simple digital yes/no circuit, or a more complex circuit that reads various inputs to produce a variety of outputs.

In 1989 Citroën released the XM with *Hydractive* suspension. It was not a true active system, but a reactive system. It used inputs from the motor, the gearbox, suspension arms and the driver (throttle and brake) to decide how to control the six hydro-pneumatic springs and the four struts in the suspension system. The result was a car that could ride like a plush “boulevard cruiser” or change to a sportier handler with minimal body roll. This complex system has been further refined over the years.

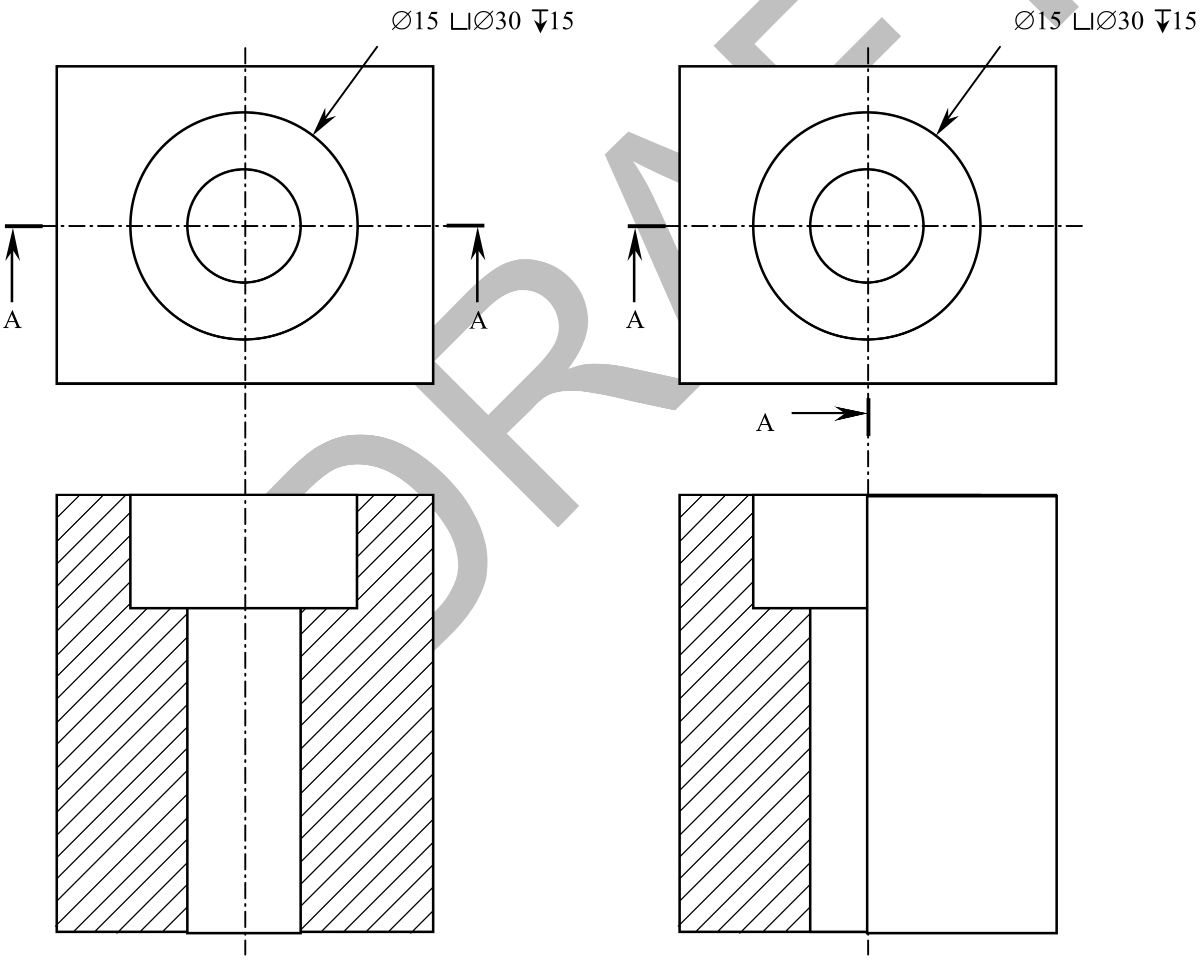
Control technology is used to trigger safety devices like ABS brakes and airbags. As a wheel begins to lock, the computer reduces the brake pressure, preventing the wheel from locking and the car from skidding out of control. ABS now forms part of Dynamic Stability Control (DSC) on cars, where the DSC can operate individual brakes to improve the cars response to the driver’s inputs.

Communication

Sectional Views

Summary of Sectioning Rules

- Half section means half the sectioned view is sectioned, while a full section means the section covers the whole of that view.
- Features likes ribs/webs are not sectioned, this avoids confusion about the final shape.
- Bolts, nuts, studs and shafts are not sectioned.
- Hatching lines are thin dark lines.
- Hatching lines are usually at 45° unless one side of the shape is at 45°.
- If different parts are sectioned but are adjacent first use the opposite 45° orientation, then select other common angles such as 30° or 60°.
- Hidden detail should not be shown on the sectioned view



Section A-A

Section A-A

Fig. 2.40: *A through hole with counter bore, shown on the left as a full section, while the right shows a half section.*

Sectioning threads

When threaded holes are sectioned specific rules come into play. Fig 2.41 displays three examples. First a through threaded holes is shown, then a blind threaded hole is shown, not the 120° triangular bottom to show where the drill stopped. Finally a through threaded hole is shown but now a bolt with a full length thread is inserted with a washer. Note how the hatching lines don't pass through the thread where the bolt has engaged it, cause we don't section bolts.

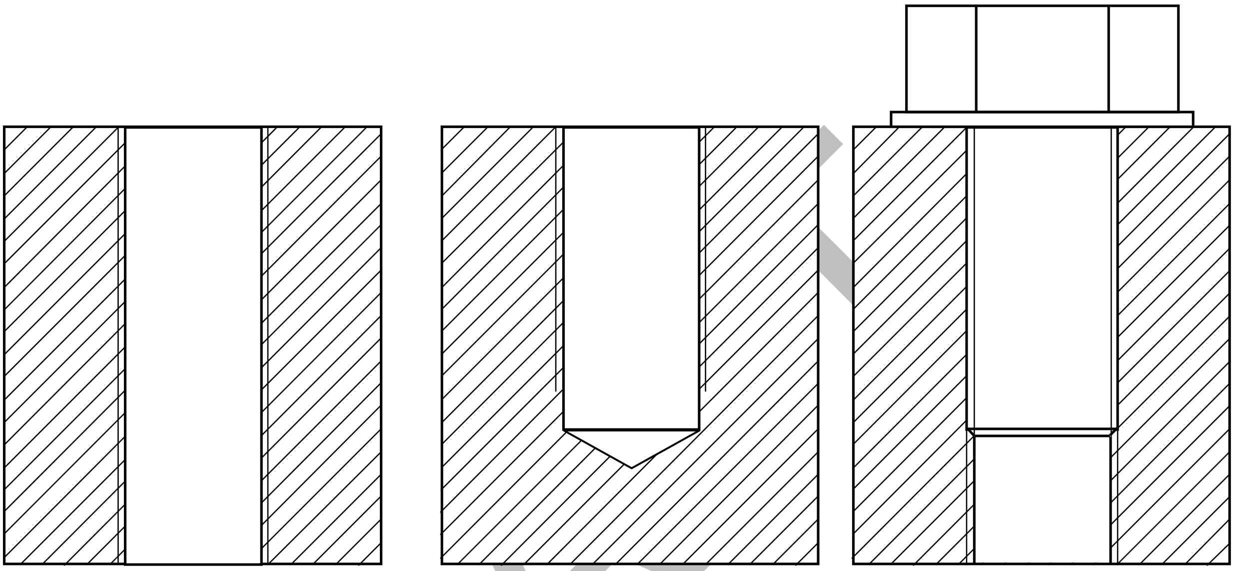


Fig. 2.41: *Three examples of sectioned threaded holes: left, a through hole; centre, a blind hole; and right, a threaded through hole with a bolt in place.*

Engineering Report

Using the outline from Chapter 1, develop an engineering report on the following topic.

Currently the bicycle industry has many choices of materials from which to manufacture their frames. Make a judgement on the best material for a small handbuilt bicycle company, currently making 500 bicycles a year. The materials to choose from are Reynolds 853, Titanium alloy, 7005 Aluminium alloy, Carbon fibre and 4130 chromium molybdenum steel.

Your report should consider the strengths of the materials, the fatigue resistance, its resistance to bending and the ease with which it can be joined.

Remember this is a small company, and cost is important, but so is weight, so the company wants to keep weight and cost down.

Additional References

This list of useful references allows students further investigation. Any highly recommended book or website has two stars next to it.

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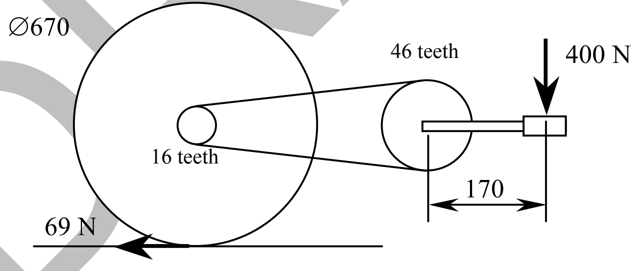
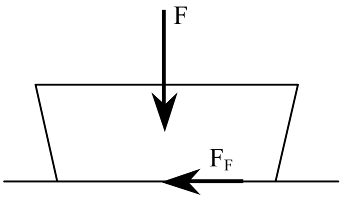
Review Questions

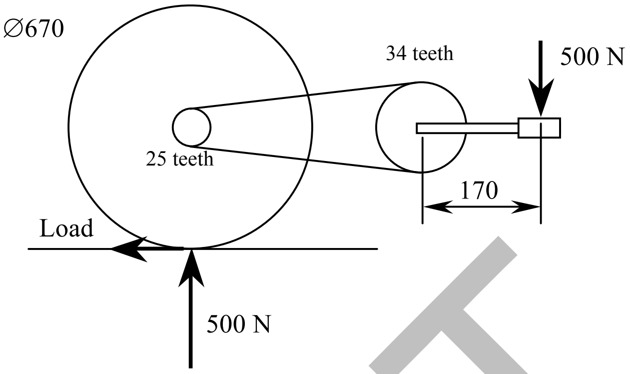
1. What was the first real bicycle?
2. Why did early bicycles use front wheel drive?
3. Why did the Old Ordinary get developed? What were its advantages and disadvantages?
4. Why was the Safety Bicycle such an important development?
5. What important development for transport devices occurred in 1888?
6. What is a mountain bike?
7. The Moulton bicycle and the Brompton folding bicycle use smaller wheels than standard bikes, what are the advantages and disadvantages of this feature?
8. What are the advantages and disadvantages of recumbent bicycles?
9. The Ford Model T is generally considered the most important car ever. Why is this so?
10. Why was the Mini such a revolutionary car design?
11. Why was Stephenson's *Rocket* important?
12. What were the advantages of the Garret locomotive?
13. What were Shay locomotives used for?
14. Why do diesel/electric trains use electricity to provide traction instead of a gearbox, like cars and trucks?
15. Why are newer alloy steels still desirable in bicycles?
16. Describe why are aluminium alloys used so extensively in bicycles?
17. Explain what makes carbon fibre composite frames desirable for racing bikes?
18. List two environmental impacts of the car?
19. Imagine that the car is banned tomorrow in Sydney. What would the effects be? What would the transport solution be?
20. A bicycle drive system is shown below. Determine the efficiency of the drive system for the load and effort shown.



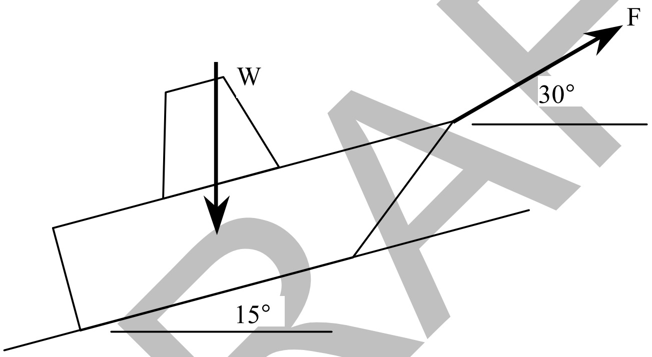
21. Define the normal reaction.
22. A bicycle brake pad is forced against the rim to stop the bicycle. What would the applied force be to produce a 100N braking force if μ =0.6?



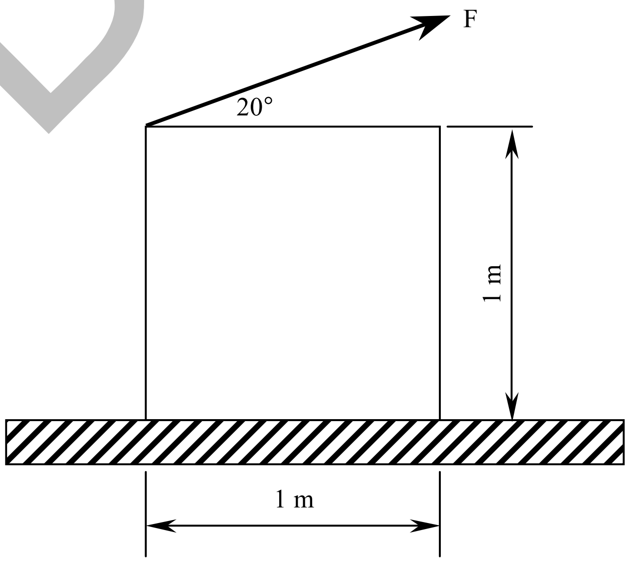
23. A bicycle drive system has an efficiency of 95%, determine the force at the back wheel if an effort of 500 N is applied to the pedal. If the coefficient of friction between the tyre and the road is 0.6, and the reaction between the road and the rear tyre is 500 N, will the wheel slip?



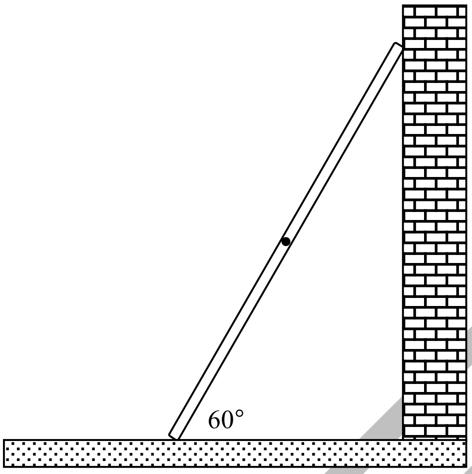
24. What force would be needed on the rope to (a) drag it up the slipway, or (b) stop the 1 tonne boat sliding down the slipway? (μ =0.2)



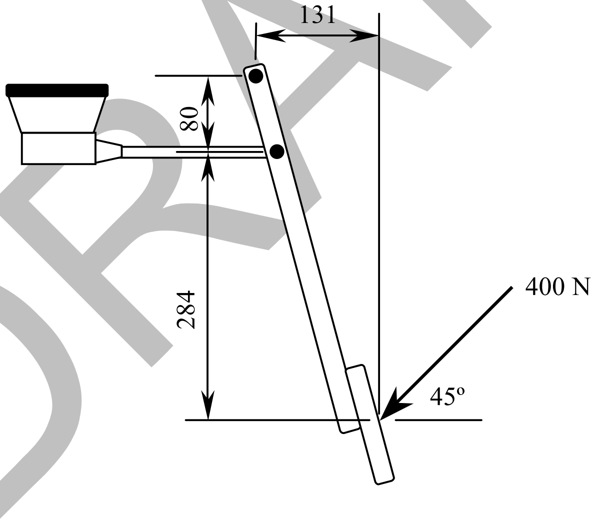
25. A 200 kg crate of vehicle parts is shown below. It is meant to be lid along the floor by the force, *F*, as shown. If the coefficient of friction between the crate and the floor is 0.3, calculate the minimum force that will make the box tip, and determine whether the box will tip or slide first.



26. The 5 m ladder of mass 20 kg is shown and rests against a rough wall and a rough floor. If the coefficient of friction between the wall and the ladder is 0.2, determine the coefficient of friction between the ground and the ladder to keep the ladder in place.



27. A brake pedal for a car is shown below; determine the reaction at the pivot pin and the load in the pushrod.



28. A 1.5 tonne car rests on a hill 50 metres from the bottom, and the hill is at an angle of 5°. The handbrake of the car lets go and it starts to roll down the hill, determine the speed the car will be travelling at when it reaches at the bottom, if the average resistance to rolling is 200 N.
29. A 10 kg bicycle plus the 70 kg rider are travelling at 25 km/h at the top of a 100 m hill, the bicycle coasts down to the bottom, of the hill where the speed is now 60 km/h. Determine the total resistance to motion if the rider descended a vertical height of 9 m while travelling down the 100 m hill.
30. Define potential energy.
31. What is work in engineering terms?
32. Explain what is meant by the terms power and torque?

33. A motorcycle and rider of total mass 250 kg is ascending a hill of gradient 1 in 15 at 80 km/h. Determine the power needed by the motor if the motorcycle is to maintain this velocity against a total resistance of 200 N.
34. A diesel-electric locomotive can provide a maximum tractive force of 4 MN, the loaded wagons weigh 60 tonnes. Rolling resistances are 50 N/tonne. Determine the maximum amount of wagons the train can pull on flat ground at 100 km/h, and how many it can pull up a 1 in 50 incline at the same speed.
35. How do process annealing and full annealing differ?
36. What is normalising?
37. Why is it possible to harden steels?
38. How is it that cooling in air can harden some steels?
39. What is Bainite?
40. What effect does forging have on the macrostructure of an item?
41. What are the advantages of cold rolling over hot rolling?
42. Explain the sand casting process.
43. How does direct and indirect extrusion differ?
44. Explain why powder forming is used.
45. What are the advantages of aluminium lithium alloys?
46. What is brass?
47. Explain why, in terms of structure, cartridge brass is more ductile than Muntz metal.
48. Explain what is meant by the term aluminium bronze.
49. Describe the process of precipitation hardening?
50. List four types of glasses. What are their properties?
51. Explain the difference between thermoplastics and thermosets.
52. What are engineering textiles?
53. Why is Aramid important? Where is it used.
54. Explain the process of injection moulding.
55. How do coal and nuclear power generation differ? How are they similar?
56. What does the term rectification mean?
57. Explain how pulse width modulation is used to control motor speed.
58. Describe how control technology is used to make cars safer.