ENG089

Fabrication
Information Book

Learning Resource
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Chapter 1 –
Introduction to trade history

Introduction

There is general agreement that the metal fabrication trade began somewhere around the 18th century, at the time of the industrial revolution of Britain.

The introduction of the steam engine during this period required a boiler as an essential part of the engine. These engines and their boilers were created by such masters as Thomas Savery in 1698, Newcomen in 1700, and Hancock in 1720. James Watt produced the first truly successful boiler for his ‘steam wagon’ in 1769.

The boilers for these engines were made from plates of metal that were cut to shape, formed up on forges by ‘blacksmiths’ and then joined together using rivets. The methods used to mark, cut and shape material and then join it together established the craftsperson known as ‘boilermaker’.

In this chapter we will look at the following.

- Introduction
  - trade evolution
    - new joining processes
    - scope of the trade
  - apprenticeship (defined)
    - apprenticeship terms
  - training plan.

Trade evolution

The first recorded trade union meeting of boilermakers took place on the August 20 1834 in Manchester, England. The skills that were acquired by the early boilermakers had now developed into new techniques and outlets in the industries of railways, transport and construction.

It was considered part of the trade to fabricate metal machines, but also steel structures from plates, angles and sections that were being produced by the expanding steel industries.

There was also increased energy demand, more power stations were built, the mining industry developed rapidly and transport systems such as locomotives and ships were required. These events further aided the expansion of the metal fabrication trade, to the point that today the metal fabrication tradesperson may be found at work in virtually every sphere of the metals, mining and manufacturing industry.
The skills of the old boilermaker were necessary in steel fabrication workshops to mark out, cut, punch, drill, form up and assemble, and then join the material together as required. As the metal fabrication trade began to evolve, many new innovations were being introduced in methods of cutting, shaping, assembly and joining of components.

Riveting was originally used to join material together in a process that consisted of hammering over the ends of a white hot cylindrical piece of steel placed in holes drilled for the purpose. Bolts were also used, and these were developed from the idea of the screw, which was used as far back as the 14th century. Welding soon became the main method used to join metals together.

The techniques of material handling, cutting and assembly were also being continuously altered as new materials, designs and processes were introduced. Large capacity guillotines, rolls and punches were developed within the trade to enable the boilermaker to undertake an even broader range of projects.

The old trade term of ‘boilermaker’ has evolved over time into the general term of ‘metal fabricator’.

The metal fabrication trade also encompasses some other traditional terms such as structural steel fabricator, sheet metal worker and first class welder.

As can be seen, these metal fabricators still require the general skill set of the old boilermaker trade, such as:

- working safely
- reading drawings
- marking out material
- cutting material
- forming and shaping material
- assembly of parts
- welding components
- repairs
- corrosion protection of parts.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<td>non-ferrous</td>
<td>the term given to metal that does not contain iron</td>
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Metals commonly used in the metal fabrication trade range from ferritic-based plain carbon steel and low alloy steels, to high alloy steels such as manganese steel or stainless steel. Non-ferrous materials such as aluminium and its alloys and/or copper and its alloys may also be used, according to application.
New joining processes

For centuries, the only method used to join metals by metallurgical process was forge welding. This was a crude and cumbersome blacksmith type operation, in which heated metals were pounded or rammed together until fused. The joining of large heavy sections required large fires, great skill and hard work for successful welds.

It soon became evident that forge welding could not fulfil the requirements of the repair and manufacture of new metal products. The increased demand for steel products forced the development of new methods of joining metals.

The electric arc was discovered by Sir Humphrey Davy in 1801, while he was experimenting with electricity for illumination. The electric arc was apparently used to melt small pieces of iron together in 1860 by an Englishman named Wilde. The intense heat of the arc was used by Auguste de Meritons in 1881 for melting lead battery plates together with a carbon electrode. The process was developed further by the Russian scientists Mikolai Barnados and Stanislov Oliszewski in 1885.

Barnados’ carbon arc process used an electric arc to create a layer of molten liquid between the edges of the metal and was adopted by some workshops. General acceptance of the carbon arc process was slow, because of carbon pick-up from the electrode.

In 1887 an American, Charles Coffin, and another Russian, N G Slavianoff (while working independently with existing welding methods), decided to replace the carbon rod with a metal electrode. The metal electrode provided the heat and also melted down to provide filler metal for the joint. In the United States, Elika Thomson patented an electric welding process that used a transformer in 1886.

By the turn of the century, bare metal electrode arc welding was a fairly common method of repair. The welds produced were not as strong as the parent metal, the arc often overheated the weld metal, and the deposited metal was embrittled by reactions with the air.

In an attempt to overcome these difficulties, an electrode using a coating of asbestos and sodium silicate as a binder was developed by Swedish engineer Oscar Kjillberg in 1907. The coating stabilised the arc, however it did little to improve the weld deposit. In 1912 a more successful electrode coating was developed in England by Arthur Strokmonger. Cellulose coated electrodes were introduced in the 1920s, and in 1927 the development of an extrusion process that applied the flux covering to the core wire produced the forerunner of the modern electrode.

Resistance welding and oxy-acetylene welding (OAW) processes were also developed in the same period as electric arc welding. The resistance welding process was developed during experiments being conducted by Elika Thomson at the Franklin Institute, Philadelphia, in 1886.

The process used a high density current and local pressure to form a weld. It was from these experiments that the complex, highly automated resistance welding processes of today have developed.

The oxy-acetylene flame was discovered by a French chemist named Le Chatelier in 1835, and he noted that the combustion of oxygen and acetylene produced a flame of intense heat. A year later, the commercial production of oxygen from liquid air and acetylene from calcium carbide ensured supplies of gas for the process. In 1901, blowpipes of a practical type were introduced and adopted by industry to cut and weld metals.
The oxy-acetylene process was used for many years, especially in repair work, because of its great portability. It is still in use in modern times, although in a reduced capacity and mainly for repair or maintenance. Oxy-acetylene cutting is still commonly used in industry while the specialised welding work that was done with oxy-acetylene equipment has been superseded by the gas tungsten arc welding (GTAW).

The GTAW welding process was developed in 1930 by Henry M Hobart and Phillip K Devero. They used a non-consumable tungsten electrode to create an arc and provided an external supply of shielding gas to protect the molten weld pool. The filler wire was introduced manually to the joint in the same manner as oxy-acetylene welding.

Experimental work conducted in the 1930s attempted to mechanise the arc welding process. The use of a granular flux blanket around an arc created from a continuously fed bare steel electrode led to the development of the submerged arc welding process in 1935. By 1940 submerged arc welding (SAW) was well accepted and used in shipbuilding industries.

In 1948 another variation of the arc welding process occurred, when an external gas supply of shielding gas was adapted to a wire feed system. This process was referred to as metal inert gas welding (MIG). This has become gas metal arc welding (GMAW) because of the use of active shielding gas. The welding processes were continuously developed and improved and the desire for greater applications led to the introduction of self shielding, flux cored electrodes in flux cored arc welding (FCAW), in 1959.

In conclusion, the welding industry went through a process of rapid development between 1900 and 1935. By this time almost all of the welding processes in common use today had been invented. They have been further developed and accepted by industry through the years.

**Scope of the trade**

The standard qualification term used to describe a metal fabrication tradesperson is now *'Certificate III Engineering' – Metal Fabrication* (stream). The streams available are heavy, light, or welder.
(a) Pressure vessels spherical

(b) Pressure vessels cylindrical

Fig 1.1 – Examples of fabrication
Fig 1.2 – Examples of fabrication – bridge construction
Fig 1.3 – Examples of fabrication – construction and earthmoving equipment
Fig 1.4 – Examples of fabrication – storage
Fig 1.5 – Mechanical handling equipment
Fig 1.6 – Examples of fabrication – communications

Fig 1.7 – Examples of fabrication – electrical power transmission
Chapter 1 – Introduction to trade history

Apprenticeship (defined)

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<th>Definition</th>
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<td>apprenticeship</td>
<td>a system of training regulated by law or custom which combines on the job training and work experience while in paid employment with formal off-the-job training. The apprentice enters into a contract of training or training agreement with an employer which imposes mutual obligations on both parties. Traditionally, apprenticeships were in trade occupations and were of four years’ duration. In WA, metal trades are now 3.5 years</td>
</tr>
<tr>
<td>guardian</td>
<td>a court appointed person who takes care and responsibility for the affairs of another (welfare, legal, financial etc)</td>
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The term ‘apprenticeship’ means that an employer, the apprentice and their guardian enter into an agreement whereby the following applies.

1. The employer agrees to teach the apprentice the craft or occupation by providing instruction in a gradual and complete manner over a specified time period and shall give the apprentice reasonable opportunity to learn and receive such technical trade and general instruction and training as may be necessary.

2. The apprentice agrees to accept the instruction provided in the chosen craft or occupation and shall conscientiously learn to the best of their ability such technical, trade and general instruction in addition to the teaching that may be provided by the employer.

3. The guardian agrees to foster and support this arrangement.

There is an on-the-job training and learning commitment and requirements. An apprentice should work in a safe manner, be punctual, willing and conscientious at work. They should maintain steady progress throughout the apprenticeship period in order to complete all of the on-the-job training and learning as required.

The off-the-job training and learning requirement of apprentices is provided by technical training institutions such as Technical and Further Education Western Australia (TAFEWA), or any other registered training provider. Attendance at this off-the-job training and learning component by apprentices is compulsory in Western Australia. The terms, attendance modes, duration of attendance and frequency of attendance are currently governed by the Industrial Training Act 1975 and the Industrial Training General Apprenticeship (1981).

The registered training provider will issue a Statement of Attainment for any Units of Competency (UoC) or Competency Standard Units (CSUs) that have been achieved by the student. The registered training provider will also issue a final certificate (Certificate III of Engineering) and the trade certificate by the WA Department of Education and Training (DET).
Apprenticeship terms

Metal fabrication trade apprenticeship agreements are generally over a fixed term of three and a half years. This agreement may however be reduced or extended according to regulations. An apprentice can also have the agreement cancelled, suspended or transferred according to the conditions mentioned in the Industrial Training General Apprenticeship regulations (1981).

A reduction in the normal term of apprenticeships is available to those who meet the following conditions.

1. By agreement between all concerned parties.
2. Have reached certain levels of secondary education.
3. Have achieved more than satisfactory progress.
4. Those who have already reached competency in some or all of the required units and can thus claim recognition of these competencies.
5. Those already working at trade level and feel they have achieved the required level of practical and academic ability. They can thus seek to obtain independent endorsement of their ability to reach the required standard of workmanship by the appropriate Trade Advisory Board or Training Provider.

An extension in the normal term of apprenticeships may occur when:

- the apprentice has not achieved satisfactory progress
- the apprentice has not reached specified levels of competence.

| competency standard | an industry-determined specification of performance which sets out the skills, knowledge and attitudes required to operate effectively in employment. Competency standards are made up of units of competency, which are themselves made up of elements of competency, together with performance criteria, a range of variables, and an evidence guide. Competency standards are an endorsed component of a Training Package. Source: DEST glossary of terms 2007. |
Chapter 1 – Introduction to trade history

Training plan

The apprentice, the workplace representative and the training provider are required to agree to and sign a ‘Training Plan Outline’ (TPO). The TPO lists the units that an apprentice is to be trained in, and must achieve competency in, over the duration of the apprenticeship.

A Unit of Competency describes what an apprentice is expected to be able to do.

Assessment for compliance to a UoC can be undertaken on-the-job, off-the-job (or in combination) only by a certified assessor.

If an apprentice fails to demonstrate what they should be able to do (ie demonstrate competence in a unit from the TPO), he/she may be allowed further time to develop the skills required before being re-assessed.

An apprentice that has non-compliance for a unit above a given time period will be required to repeat training and assessment.

When an apprentice has a poor attendance record or has a poor attitude towards maintaining steady progress in either the on-the-job training in the workplace or in the off-the-job training at a training provider, a review officer may become involved.

An apprentice who fails a number of units, or fails to make satisfactory progress, may be deemed to be at risk of cancellation or suspension.

An apprentice who has an adverse progress report, poor attendance, bad attitude, or has committed a serious offence will be at risk of having the apprenticeship cancelled.
Chapter 2 – Tools of the trade (hand)

Introduction

Every trade has its own methods of operation, and specific tools that apply. The metal fabrication tradesperson is required to have knowledge of and be able to use a diverse range of tools that are considered to be specific to the trade.

In this chapter we will look at the following.

- Tools of the trade
  - marking-off tools
  - hammers
    - hand hammers
    - sledge hammers
  - chisels
    - types of chisels
  - hacksaws
  - files and filing
    - types of files (shape)
  - thread cutting
  - spanners
  - snips
  - screwdrivers
  - gripping and clamping tools
    - types of pliers
    - types of clamping devices.
Chapter 2 – Tools of the trade (hand)

Marking-off tools

Marking-off is an important responsibility of the metal fabricator. It involves taking an idea or design, usually provided as a drawing or material cutting list, and transferring its shape and dimensions, at actual or scale size, on to the required working material.

Common marking tools are:

- rule
- scriber
- try square/combination square/plate square
- tape measure
- dividers
- calipers
- level
- straight edge
- chalk/chalk line
- adjustable bevel
- surface gauge
- trammels
- plumb bob
- centre punch.

All such tools should be handled with extra care so that they remain accurate and efficient at all times.
Rule
Metal fabricator’s rules are made of best quality steel and may be fixed at 300 mm in length, or 600 mm in length and folded at the 300 mm mark. The better types are made from a rustless steel or are treated to prevent corrosion. The rules are graduated in millimetres, and may be used as a straight edge on small work or for joining up a number of points to form an arc.

When used in the latter manner, care should be taken because these rules will fracture easily. Some optional folding rules also have a line of chords for marking-off angles and circumference calculations.

Straight edges
The straight edge is very useful when marking large work, where surfaces are to be tested for straightness and flatness, or where components have to be lined up. They are made of good quality steel and accurately machined with parallel edges, one of which is usually bevelled.

Straight edges are available in lengths ranging from 300 mm to over two metres. A good one metre rule may also be used as a straight edge. Straight edges should be carefully stored and never dropped, hammered or allowed to come in contact with the arc of the electric welding process.

Chalk/chalk line
Engineers’ chalk is ideal for marking out on steel, provided the end is kept sharp. The engineering chalk line is easily seen on steel products and is permanent enough to allow for any mechanical cutting, thermal cutting, forming, pressing or assembly operations to be carried out. Engineering chalk lines do not damage the material, can be easily smudged and are easily altered or removed.

Chalk lines are made using string line and soft chalk and these can be used for laying down straight lines. Long lines can be struck by stretching the chalk line taut and then holding down and flicking lengths of not more than four to five metres approximately. Assistance will be required if a long line is being marked.

Good soft chalk gives a better mark and imparts longer life to the chalk line. Avoid hard or greasy chalk.
Limitations of chalk lines

Chalk lines do have some limitations, such as:

- they can be erased accidentally
- string may make thick or double lines
- they maybe inaccurate in windy conditions
- visibility can decrease in the middle, over long distances
- they need witness centre punching for permanency
- they can only be used on flat surfaces
- they can be hard to see on some non-ferrous metal.

Fig 2.3 – Using a chalk line

Scriber

Scribers are used in conjunction with straight edges, squares, etc to mark lines on work. Scribers are usually made in the workshop from a piece of spring steel about 5 mm diameter. One type commonly used has both ends pointed, one end being bent at right angles to a length in order to give a greater range of usefulness. The ends are hardened to give hard durable points. Scribers with a knurled handle into which a hardened point is secured can be purchased (Fig 2.4).

Fig 2.4 – Scriber

Limitations of scribed lines

The scribed line:

- is hard to see when you're thermal cutting (you should use witness centre punching)
- can cause corrosion on stainless steel
- should only be used on ferrous metals.

The surface of the metal must be repainted if a mistake is made.
**Squares**

Squares are used to mark lines, or test surfaces at 90 degrees (°) to each other.

The *try square* consists of two parts; the stock and the blade. The blade is fitted accurately at 90° into a slot in the stock, which must be wide enough and sufficiently heavy to sit firmly on the marking-off table or against a surface when in use. For bench work, the blade length varies from 75 mm to 300 mm with the stock being about two-thirds the length of the blade.

A *combination square* consists of a sliding rule fitted to a combination 45° and 90° angle and may be used to set bevel angles, right angles and edges distance or gauge lines. A good quality combination set also allows an optional adjustable protractor or centre finding attachment to be fitted to the sliding rule (Fig 2.5).

---

**Fig 2.5 – Squares**

(a) Try square

(b) Combination square
There are two types of **plate squares**, one bounded by three sides and made from flat plate, and the other with two legs at 90° to each other. Both are used extensively for marking-off and setting up for tacking and welding.

**Adjustable bevel gauge**

Used to reproduce or compare angles. The simple bevel consists of two parts; the stock and the movable, slotted blade. The blade may be clamped at any angle to the stock by tightening the locking nut (Fig 2.7).
Tape measure
Tape measures are used to measure over long distances and can be made from steel, fabric or synthetic materials.

Fig 2.8 – Tape measure

Dividers
Dividers are used for scribing circles or arcs, or for transferring distances taken direct from a layout or measuring distances between points. They are usually of the spring type (Fig 2.9), having two straight pointed legs and should be sharpened only on the outside edges of the points. Dividers should be closed to zero before grinding the points. Adjustments may be made by means of the knurled nut, which may be either solid or split.

Fig 2.9 – Spring divider
Trammels

A trammel (Fig 2.10) is a tool used for scribing arcs and circles that are larger than can be scribed with normal dividers.

A trammel consists of a long beam, along which two heads that are fitted with hardened points may be moved.

![Fig 2.10 – Trammel](image)

Calipers

These tools are used for measuring distances between, or over, surfaces; for comparing or transferring sizes, etc. They are made in various types, such as those used for taking or checking either inside or outside measurements, some of which are shown in Fig 2.11 (a) and (b).

In the firm joint type caliper, the friction at the joint retains the legs in the set position. These calipers are adjusted to size by tapping, and must be carefully handled to prevent altering the correct setting. Improved types of firm joint callipers are available, in which the final adjustment can be made by means of an adjusting screw.

![Fig 2.11 – Firm joint calipers (a) outside and (b) inside](image)
In the adjustable spring type caliper, the legs are adjusted by the action of a spring against an adjusting nut. This type can be adjusted more quickly than the firm joint calipers (Fig 2.12). The greatest care should be taken to prevent 'springing' when using this type, because the touch is not as definite as with the firm joint calipers.

![Spring calipers](image)

**Fig 2.12 – Spring calipers (a) outside and (b) inside**

Jennies, sometimes called oddlegs, have one caliper leg and one divider leg and are made in various types. One type (see Fig 2.13) has an adjustable point, a lock joint and a fine adjustment attachment.

They are used mostly for scribing lines parallel to an edge or for finding the centre of circular work.

![Jennies](image)

**Fig 2.13 – Jennies**
Plumb bob

The plumb bob is used to locate or check a vertical line or surface. They are made in a variety of shapes and sizes that all take the form of a pointed metal weight, which is suspended by a chord secured in the head of the plumb bob. They are used extensively in building construction for setting vertical surfaces or for plumbing columns etc (Fig 2.14).

![Plumb bob](image)

Fig 2.14 – Plumb bob

The level

The level is used to test, adjust or check horizontal or vertical surfaces. The frame of an engineer’s level is made of metal, the flat base being frequently grooved to enable the level to be used on round shafts. To check a level for accuracy, turn it end for end on a flat surface. If the level is accurate, the two readings will be the same (Fig 2.15).

![Level](image)

Fig 2.15 – (a) Engineers’ level, and (b) spirit level
Centre punches
Centre punches are hand tools that are designed to be used with a hand hammer. Good quality centre punches are made from high carbon steel with hardened and tempered points, and usually the shank is knurled to give a secure grip.

The safe use of centre punches depends on holding them correctly, hitting them squarely and keeping the head free of burrs that lead to mushrooming (Fig 2.16).

Fig 2.16 – Safe use of centre punch

The metal fabrication tradesperson uses two sizes of centre punches. The smallest is called a prick punch, and is used to make witness marks on scribed lines. These light centre punch marks make it easier to:

- see accurate marking out lines
- accurately locate centre points of holes before heavy centre punching
- accurately locate the pivot points for scribing circles.

Large centre punches are much larger than prick punches, and are used to:

- make heavy centre punch marks to locate a hole centre and make it easier to start the drill accurately
- make heavy centre punch marks on scribed lines
- mark the relative position of fabricated components for matching, making assembly easier.
For accuracy, keep the centre punch point sharp. After centre punching, check that the centre punch mark is accurate. If not, the centre punch mark can be moved over by striking the centre punch at an angle until the mark is accurate.

Fig 2.17 – Centre punch marks
Hammers

Hammers are classified into two main groups:

- **Hand hammers** used in the engineering trades are usually referred to as engineers’ hammers or ball pein hammers. These hammers vary in mass from 125 g to 1 000 g. The smaller hammers are used for marking out and the larger ones for chiselling, plate levelling, driving drifts, etc.

- **Sledge hammers** are available in a number of shapes, ie cross pein, straight pein, double faced and ball pein. In this group we can include all hammers designed for double handed techniques such as plating hammers and small, medium and large sledge hammers.

![Hammer Shapes](image)

Fig 2.18 – Sledge hammer shapes, (a) cross, (b) straight, (c) double, and (d) ball

The mass of these hammers ranges as follows:

- 1 300 to 2 250 g (1.3 kg to 2.25 kg) sledge
- 3 200 to 4 500 g (3.2 kg to 4.5 kg) medium sledge
- 5 000 g (5 kg) and over for large work.

The class of hammer depends on the type of work and the size of hammer depends on the size of work.

Three important features of a hammer that determine its satisfactory use are:

1. length and shape of handle
2. method of wedging
3. shape or contour of face.

**Length and shape of handle**

Hand hammer handles

<table>
<thead>
<tr>
<th>Hammer head mass</th>
<th>Length of handle</th>
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<tr>
<td>125 g to 250 g</td>
<td>250 mm to 330 mm</td>
</tr>
<tr>
<td>1000 g</td>
<td>330 mm to 380 mm</td>
</tr>
<tr>
<td>Sledgehammers 2000 g and over</td>
<td>750 mm to 900 mm</td>
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</tbody>
</table>
Well seasoned, strong wood of good elasticity is required, the best handles being made of hickory or ash. They should be about 320 mm in length and the centre line of the handle should be at right angles to the head. The shape of the handle is important because on it depends the ‘fall’ or feeling of flexibility and power that accompanies each blow when the hammer is used. A hammer with a good ‘fall’ can be used for a long time without fatigue.

The handle should be reduced to a rather slender throat, with one end increased in size to fit the eye, the other end being a suitable size to fit the hand of the workperson.

![Fig 2.19 – Parts of a hammer handle](image)

**Method of wedging**

Most new hammers have a wooden wedge lengthwise and a steel wedge crosswise. This is to ensure that the handle end completely fills the head and ensures lack of movement.

![Fig 2.20 – Hammer wedging](image)

**Shape or contour of face**

Marking-off hammers usually have a flat face with slightly rounded edges. Hand hammers and sledge hammers usually have a convex face so that they will not mark the plate unduly during the operation of levelling (Fig 2.21).

![Fig 2.21 – Hammer faces](image)
Chisels

Types of chisels

There are four common types of cold chisels in general use (Fig 2.22). They are called cold chisels because they are used to cut metal in the cold state.

1. Flat chisel.
2. Cross cut chisel.
3. Round nose chisel.
4. Diamond point chisel.

Chisels are made of high carbon steel and alloy steels, of which there are many commercial grades such as ‘double griffin’, 3% nickel, cast steel etc. The forging and heat treatment of these tools requires careful attention. The chisel must be hardened sufficiently so that it will cut without breaking, chipping or losing its edge. There is always a quantity of soft metal behind the hardened cutting edge to absorb the shock of the blow.
Sizes

The size of the flat chisel is generally given as the width of the cutting edge. For instance, a flat chisel with a 20 mm cutting edge would be called a 20 mm flat chisel. A crosscut 10 mm on the width of the cutting edge would be a 10 mm crosscut. Other chisels are similarly measured.

The length varies from 160 mm upwards according to individual taste. They can also be made up into lengths 660 mm and over, then they become known as chisel bars.

Grinding chisels

Like any other cutting tool, the edge of the chisel must be ground correctly if it is to give satisfactory service. The angle of the cutting edge will vary according to the metal being cut.

The cutting angle used for chisels varies between 50 to 70°:

- brass – 50°
- cast iron – 70°
- mild steel – 60°.

When grinding, enough metal must be left at the back of the cutting edge to carry the shock of the blow from the hammer and at the same time give the most efficient cutting edge.

![Diagram of chisel angles](image)

**Fig 2.24 – Chisel angles** (a) angle nomenclature, and (b) angle values

Faults in grinding chisels

1. Chisel too thick at cutting point – This causes cutting resistance and the chip to break continually, making it difficult to preserve a flat surface.
2. Angle of chisel too acute causes the edge to break or fold up.
3. Overheating of chisel during sharpening – Causes loss of temper and renders the cutting edge soft and useless.
Uses of chisels

- **A flat chisel** is used for chipping large surfaces, cleaning off welds and general work.
- **A crosscut** is used for cutting key ways or wherever a rectangular groove is required. Crosscut chisels can be used in conjunction with a flat chisel to reduce surfaces.
- **A round nose** is used to cut grooves with round corners, such as groove for the backing run of a weld. Also for picking out the remains of broken studs and stays, etc.
- The sharp vee groove cut by the **diamond point** chisel provides a starting point for a break when removing ‘bushes’ or ‘ferrules’. A diamond point chisel is also useful for chipping out weld or working in corners.

General handling techniques for chisels

The tool can be held with the thumb facing either in the direction of the head of the chisel, or facing the cutting edge.

It is important to watch the cutting edge or more particularly the line being chipped to. The head of the tool should be struck automatically without watching it.

Safety precautions to ensure safe operation of chisels

1. Keep the head of the chisel free from sharp burrs or excessive ‘turn over’ (Fig 2.25).
2. Do not chip in the direction of others in the vicinity.
3. Wear goggles to protect your eyes.
4. When approaching the end of a cut, the chip should be removed by a series of light hammer blows on the chisel head. This precaution prevents chips flying across the shop, and possible damage to your hands or skinned knuckles as the chip is finally removed.

![Fig 2.25 – Chisel head (a) dangerous – excessive turn over, and (b) correct](image-url)
Hacksaws

The hand hacksaw consists of a fixed or adjustable metal frame for carrying the blade of the saw, and a metal handle. The blade is tensioned, or held tightly, by means of a tensioning screw and nut fitted to the frame. Pins are provided – one on the tensioning device and the other on the fixed part of the frame, to engage with holes at the ends of the hacksaw blade.

![Fig 2.26 – Adjustable framed hacksaw](image)

**Uses**

Hacksaws are used in the engineering trades as metal cutting tools for cutting stock bars and for rough shaping parts of irregular form. Advantages of their use include that:

- the amount of material wasted is a minimum
- the cut edges are not strained
- the surface of the cut is suitable for finishing by hand.

**Shape and set of teeth**

The teeth of saw blades are offset alternately to right and left. This is to ensure that the width of the cut is greater than the thickness of the blade. This guards against the blade jamming when in use, and also provides clearance for the chips.

In medium and fine tooth saw blades it is usual to set two or three in one way and the next two or three teeth in the opposite direction.

Ordinary blades are hardened all over. Special ‘flexible back’ blades are hardened on the teeth only. These flexible back blades are less liable to break and are mostly used for cutting thin material or when sawing in difficult positions. They possess, however, a tendency to buckle and ‘run out of line’, which the hardened blade does not.

**Selection of correct pitch of teeth**

One of the main causes of breakage in saw blades is the teeth being unsuited to the work. The number of teeth on the blade for different classes of work is important. In general, solid materials require blades of fewer teeth than pipes, tubes etc. A softer material will require a coarser blade than a hard material.

For general practice, the following are recommended as a guide.

| Power hacksaws cutting soft steel bar etc | 14 TP 25 mm 1.8 mm pitch |
| Hand hacksaws cutting soft steel bar etc | 16 TP 25 mm 1.6 mm pitch |
| General hand work on soft materials | 18 TP 25 mm 1.4 mm pitch |
| Hand hacksaws cutting high carbon steel or cast iron | 20 TP 25 mm 1.3 mm pitch |
| Hand hacksaws cutting tubes and pipes | 24 TP 25 mm 1.1 mm pitch |
| Hand hacksaws cutting very thin tubes and sheets | 32 TP 32 mm 0.8 mm pitch |
Inserting the blade
The blade is fastened in the frame to cut on the forward stroke. Therefore, the teeth should be pointing away from the handle, and bearing hard up against the flats on the handle and tensioning portions. The tensioning wing nut should be firmly tightened, using finger pressure only. Be sure that the blade is square and true in the frame. Since edge hardened blades are flexible, they should be strained tighter than those that are hardened all over. After the first few strokes it is good practice to re-tighten a new blade.

Cutting speed
For hand hacksawing, the speed should never exceed 50 strokes per minute; 35 to 40 is generally regarded as satisfactory.

General information on the use of the hacksaw
1. Hold the work fairly close to the vice, to avoid spring and chatter.
2. Ensure that the work is firmly secured in the vice. When cutting frail work pieces, thin tubing or irregularly shaped articles, suitable clamping devices should be used. Use your own judgement on the correct amount of pressure given to the clamping of the work in the vice.
3. Hold the saw with both hands. This will restrict side movement and lessen the risk of broken blades.
4. Where possible, use long steady strokes. Vary the pressure and speed to suit the kind of material, thickness and shape of the material and the condition of the blade. Relieve the pressure on the return stroke.
5. Be careful as the finish of a cut is approached. Support any overhang, or broken blades will result.
6. Should the blade break before the cut is completed, do not attempt to finish the cut with the new blade in the old cut, or jamming of the blade will result. Either turn the work piece to a position where a new cut can be started, or where this is not possible use a partly worn blade in the old cut.
7. Keep the saw cut straight. Should the cut run, the blade is cramped and will probably break.
8. Rusty, scaly or sandy surfaces should be cleaned before attempting to start a saw cut.
9. Thin sheet metal should be clamped between two pieces of wood or any soft metal and the saw taken through all three pieces.
10. The correct and incorrect applications for tooth sizes for sawing are illustrated by the following sketches (Fig 2.27).
Chapter 2 – Tools of the trade (hand)

SOFT MATERIAL

WRONG – Too many teeth per 25 mm – the teeth will clog.

RIGHT – Correct number of teeth per 25 mm providing ample chip clearance.

HARD MATERIAL

Too few teeth per 25 mm providing insufficient cutting points in contact.

Correct number of teeth per 25 mm providing sufficient cutting points in contact.

THIN SECTION

Too few teeth per 25 mm – teeth straddling the material.

Correct number of teeth per 25 mm three consecutive teeth in contact.

Fig. 2.27 – The correct and incorrect of tooth selection
It’s important to apply the correct method of hacksawing, as shown in Fig 2.28.
(a) Teeth are pointing forward, or to the front of the frame.
(b) Start the cut as illustrated.
(c) Hold the saw with both hands.
(d) Apply the maximum number of teeth possible on the material.
(e) Keep the cut as close as possible to the vice or clamp.

Fig. 2.28 – The correct method of hacksawing, (a), (b), (c), (d) and (e)
Files and filing

A file is a piece of hardened steel having a series of teeth, in the form of grooves, cut across its face.

The teeth formed by the grooves act on the material as a series of small cutting tools when the file is passed over the surface.

File manufacture

The file manufacturing process consists of:

- forging to shape
- annealing
- grinding of the faces
- cutting of the teeth
- hardening
- tempering.

Parts of a file

Fig 2.29 shows the principal parts of a file. Some files have two faces; others, like the half round file, have only one face, the curved side being referred to as the back. The length is measured from the point to the heel and does not include the tang. The common types of files are made in various lengths.

![Fig 2.29 – Parts of a file](image-url)
Types of files (shape)
Most files derive their name from their cross-sectional shape, ie round, flat, half round etc (Fig 2.30).

- **Flat file** – used for large, flat surfaces.
- **Hand file** – has one safe edge and can file up to a shoulder without marking it.
- **Pillar file** – is narrowed and thicker than the hand file, and is used where greater pressure per unit area is required to make the file bight.
- **Warding file** – thinner than the flat file, used for filing out narrow slots.
- **Square file** – used for opening up square holes.
- **Three square file** – for squaring out corners.
- **Round file** – for opening up round holes.
- **Half round file** – used to file curved/concave surfaces.

**Fig 2.30 – Types of files**
Cut of teeth

Single cut files give a finer finish, but do not remove the metal as quickly as double cut files. They are used for draw filing, lathe filing and for filing brass and similar metals, see Fig 2.31 (a).

Double cut files have two rows of cuts at an angle to and crossing each other. They are used for general purpose filing on steel and cast iron, see Fig 2.31 (b).

Dreadnought cut files have coarse, curved teeth and are used for cutting soft metals such as aluminium and lead see Fig 2.31 (c).

Grading and coarseness

The grading of a file is also associated with its name. The grade is the coarseness of the teeth, that is the distance apart which the teeth have been cut on the file. We can list the name and teeth per 25 mm of each as follows.

- Dead smooth  – 70/80 teeth per 25 mm
- Smooth       – 50/60 teeth per 25 mm
- Second cut   – 30/40 teeth per 25 mm
- Bastard      – 20/25 teeth per 25 mm.

Safe edge is the term used for the edge of the file which has no teeth cut on it. It is used to place against the finished work in order to stop further removal of metal taking place.
Holding the file

It is most important for the beginner to learn the correct manner of holding a file. It is just as easy to learn the correct way as it is to learn the wrong way, however it will be harder to forget the wrong way and learn the correct way. In moving a file endways across the work, commonly called cross filing, the file is held as shown in Fig 2.32.

![Fig 2.32 – Cross filing](image)

For heavy filing the file should be held as in Fig 2.33 (a). For light filing as in Fig 2.33 (b) and for finishing as shown in Fig 2.33 (c).

![Fig 2.33 – Cross filing, (a) grip for heavy filing, (b) grip for light filing, and (c) grip for finishing](image)
Fig 2.34 – Correct stance
Narrow surfaces
The file should be kept parallel with the work and the stroke carried fully across the surface.

Filing of holes
In filing circular holes, a round file that is nearly the size of the hole should be used. If a small file is used there will be a tendency to produce a number of small ridges.

Filing of curves
When filing is to be done on an internally curved surface, a half round file is used. As in the case of circular filing, there is a tendency to file unevenly and a file of as large a curvature as is obtainable should be used. The file should be moved along the circumference as well as across the work.

Filing corners
When it is necessary to form a sharp corner or to file to a finished surface that stands at right angles to a finished surface, a safe edge file is used.

Draw filing
When filing by moving the file sideways across the work it is called draw filing, as shown in Fig 2.35. The file is held in both hands with the motion being at right angles to its length. Draw filing is used in finishing work.

Fig 2.35 – Draw filing
Pinning

Pinning refers to the tendency of the file grooves to pick up waste material between the teeth, forming hard pins that scratch the material. As soon as the slightest indication of pining is observed, the file should be cleaned with a file brush (Fig 2.36). Another method is to use chalk on the surface of the file.

Fig 2.36 – File cleaning

Select the correct type of file for the job in hand. **Never** use a file without first fitting a file handle over the tang. **Never** hit a file against a hard surface, as damage will occur to the teeth or the file may shatter.
Thread cutting
The threads on bolts and nuts are formed by a number of specialised processes. However, from time to time it may be necessary to produce threads in the field. The method used by trades people is hand threading using taps and dies.

Taps and dies
A tap is the cutting tool used to form an internal thread such as in a nut. The tap has a square ended shank for attachment of a tap wrench.

Each size of tap will comprise three taps which are known as:
- taper
- intermediate
- plug.

Taper tap
The taper has the last five or six threads ground away in taper fashion. This is to enable the tap to enter the clearance, or tapping-size hole in the part to be threaded, each succeeding tooth of the tap deepening the cut of the thread until the tap has entered to the end of the tapered portion, and then begins to cut the full section of the thread. For this reason, the taper tap is always the first one to be used.

In the case of ‘blind’ holes (a hole that does not penetrate right through the work), the tap is screwed down to its full extent then removed, and the intermediate and plug taps used to finish the thread to its final shape and size.
Chapter 2 – Tools of the trade (hand)

The intermediate tap
This tap is tapered for approximately three threads, and is used after the taper in order to avoid undue strain on to the plug tap.

Plug tap
This normally has the first thread ground to a taper, and is mainly used to ensure the tapping of a full thread in blind holes.

Using hand operated taps
1. Refer to a thread tapping drill size chart for the size hole to be drilled (see Table 2.1).
2. Drill the hole, making sure it is square to the surface of the work.
3. Check that correct taps are being used.
4. Use a correct tap wrench NOT a spanner (see Fig 2.39).
5. Use the taper first and confirm that the tap enters the hole correctly by checking with a try square (see Fig 2.38).
6. Use a lubricant, if applicable, to the material into which the thread is being cut.
7. After each clockwise turn, give a quarter reverse turn (anticlockwise) to break the chips into the flutes.
8. When tapping a ‘blind’ hole, be sure the tap does not ‘bottom’ on the hole or on the accumulation of chips.
9. When tapping a ‘blind’ hole, follow the taper tap with the intermediate tap and then the plug tap.

<table>
<thead>
<tr>
<th>Thread size (mm)</th>
<th>Pitch (mm)</th>
<th>Tapping drill diameter (mm)</th>
</tr>
</thead>
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<td>0.35</td>
<td>1.25</td>
</tr>
<tr>
<td>2.0</td>
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<td>1.60</td>
</tr>
<tr>
<td>2.5</td>
<td>0.45</td>
<td>2.05</td>
</tr>
<tr>
<td>3.0</td>
<td>0.50</td>
<td>2.50</td>
</tr>
<tr>
<td>4.0</td>
<td>0.70</td>
<td>3.30</td>
</tr>
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</tr>
<tr>
<td>36.00</td>
<td>4.00</td>
<td>32.00</td>
</tr>
</tbody>
</table>

Table 2.1 – metric preferred thread series (coarse) – An example of thread chart showing tapping drill size
Fig 2.38 – Using a try square to check entry of tap

Fig 2.39 – Tap wrenches, (a) bar type tap wrench, and (b) tee handle tap wrench

Dies
Hand threading of studs and bolts is commonly carried out by means of a split button die (Fig 2.40) mounted in a die holder or stock (Fig 2.41).

The split in the die allows a slight adjustment, which is carried out by the conical pointed adjusting screw in the stock.

The cutting teeth of the die are chamfered on one face to allow an easy start to the thread. The face with the chamfer is known as the ‘leading face’ and is often the face opposite to the size and name markings.
Chapter 2 – Tools of the trade (hand)

Fig 2.40 – Button die

Fig 2.41 – Die holder (stock) and die
1. Cut the bar square and prepare a small chamfer to assist in starting the thread (Fig 2.42).

![Fig 2.42 – Chamfer on bar](image)

2. Select the correct die and install it in the die holder.
3. Tighten the adjusting screw fully to open the die to its maximum.
4. Tighten the locking screws.
5. Lightly lubricate the bar with oil, grease or a specialised thread cutting compound.
6. Place the die and holder over the bar with the leading face of the die towards the chamfer.
7. Being careful to keep the die holder square to the work, turn the holder clockwise until two or three threads are completed.
8. Continue cutting the thread, allowing a quarter turn anticlockwise after each turn, to break off the chips.
9. After the full length of the thread has been cut, remove the die from the bolt and try the bolt into its nut or stud hole. If the thread is too tight, the die may be closed slightly by releasing the adjusting screw and tightening the locking screws. Again, apply the die to the bolt.
10. After completing the thread, it may be necessary to reverse the die so that the leading face is uppermost in order to cut the chamfered threads closest to the bolt head to the full depth.

**Die nut**

A damaged external thread may be repaired by use of a die nut, which is a hexagonal non-adjustable die turned by use of a spanner.

Die nuts should not be used to cut an original thread.

![Fig 2.43 – Die nut](image)
Spanners

Podger spanner
The podger spanner is an open ended spanner with a tapered point at one end, which is used for lining up (fairing) holes when assembling fabricated components. It is most commonly used when erecting structural steelwork (Fig 2.44).

Box spanner
The box spanner has a single hexagon socket at 90° to the handle. The handle also has a tapered point used to align holes. This type of spanner is used to tighten nuts or bolts in confined spaces (Fig 2.45).
Adjustable spanner

Adjustable spanners are available in sizes from approximately 100 mm (length) upwards. They are a useful general purpose spanner. Nevertheless, they should not be used where heavy torque loadings are encountered. Always use a socket, ring spanner or open-jawed spanner in preference to an adjustable spanner.

![Fig 2.46 – Adjustable spanner](image)

Using adjustable spanners
1. Tighten adjusting nuts so that the jaws are tight on the nut.
2. Use the spanner so that the thrust is on the fixed jaw.
3. Where possible, pull on the handle rather than pushing on it (Fig 2.47).

![Fig 2.47 – Using an adjustable spanner](image)
Open-ended spanners

Open-ended spanners are used for general work, particularly in confined areas where the spanner may be turned over to allow it to be used in 30° movements. The open jaw spanner is not the most suitable spanner for repetitive work or for very high torque loadings (Fig 2.48).

Fig 2.48 – Open-ended spanner

Selection of open-ended spanners

To determine the correct size of a spanner for metric threaded bolts and nuts, measure across the flats of the hexagon head of the bolt or nut. The jaw opening is equal to the distance across the flats (Fig 2.49).

Fig 2.49 – Metric spanner jaw opening

Ring spanner

The ring spanner has the advantage over the open-ended spanner of having more than twice the grip positions on the nut, thus ensuring a more positive hold and less chance of slippage.

Fig 2.50 – Ring spanner
Torque wrench

The torque wrench or tension wrench allows bolts and nuts to be tightened evenly and accurately to design torque specifications. This tool is used specifically by the metal fabrication tradesperson for tightening high strength structural bolts (HSSB). Sockets used with the torque wrench should be of the single hexagon type.

![Fig 2.51 – Torque wrench](image)

Snips

Snips are used to cut thin sheet metal. There are various sizes that are measured by their overall length and are offset, right and left-handed. Larger snips are more suitable for cutting thicker sheet metal. Cutting wire with snips will mean chipping and ruining the blades.

Types of snips:

- Universal – Used for cutting straight lines, convex and concave curves in thicker metal and can be left or right handed with either cranked or straight handles.

![Fig 2.52 – Universal snip](image)

- Straight – Used when making a straight cut or when cutting a convex curve such as cutting out a disc (where the waste metal lies on the outside of the curve).

![Fig 2.53 – Straight snip](image)
- Curved – Used when cutting a concave curve (where the waste metal is on the inside).

![Curved snip](image)

Fig 2.54 – Curved snip

- Aviation – There are three types; offset, straight and notching or trimming. These snips are usually 250 mm in length and have serrated cutting edges to stop slipping when cutting tight curves. They are available in both right and left-hand styles.

![Aviation snip](image)

Fig 2.55 – Aviation snip

**Snip safety**

When you use snips, you should:
- cut so that notches fall downward
- cut so that the scrap is away and clear of your body
- remove jagged edges caused by incorrect use of the snips
- be careful not to pinch yourself with the handle of the snips.
Screwdrivers
The screwdriver is a driving tool with a blade fitted to a handle. The tip of the blade is shaped to fit into the head of a screw and, when turned, will either tighten or loosen the screw. The two types of screwdriver tips commonly used are designed to fit either slotted head screws or recessed screws (Phillips head or Pozidriv screws).

Standard screwdrivers

Fig 2.56 – Standard screwdrivers

Standard screwdrivers are made with tips to turn screws with slotted heads. The size of screwdrivers is specified by the length of the blade and the width of the tip; they vary from 45 mm x 3 mm through to 300 mm x 10 mm.

Variations to standard screwdrivers include the ‘stubby’ or ‘stumpy’ screwdriver and the light duty screwdriver.

- The stumpy screwdriver is about 40 mm x 6 mm and is used in confined spaces.
- The light duty screwdriver is made with parallel tips and may be used by electricians. The steel blade, as well as the handle, is insulated by plastic.
Phillips head screwdrivers

This type of screwdriver is used on screws that have diagonal recessed slots or heads. Four different sizes are available to cover the full range of Phillips head screws.

Pozidriv screwdrivers are similar to Phillips head screwdrivers but they are made to fit Pozidriv screws, which have a deeper recess. It is not recommended that Phillips head screwdrivers be used for Pozidriv screws (nor Pozidriv screwdrivers for Phillips head screws), since the recess is easily damaged.

Screwdriver safety

- Select the correct type and size of screwdriver for the work. Make sure that the tip is in good condition and a good fit for the screw slot or recess.
- Keep your hand well away from where it could be injured by a slipping screwdriver. Keep the axis of the blade in line with the axis of the screw and brace small work on the bench or hold it in a vice.
- Never try to use a screwdriver as a lever, pry or pinch bar. This could break the tip or bend the blade. Bent blades are hard to keep centred.
- Never apply excessive twisting force with a screwdriver. This could break the tip or shear off the screw. Learn the 'feel' or spring of a screwdriver that is under pressure.
Keys

Keys are small fastening or unfastening devices used for specially made equipment or parts. Examples are the Allen key, drill chuck key, lathe key and hexagon driver.

Allen keys

The Allen key may be called an internal hexagon key or hex key. An Allen key is a length of heat treated hexagonal steel with one end bent at right angles, used to tighten or loosen socket head screws. The keys are made in a range of sizes to match the standard sized hexagonal holes in socket head screws. The size of the key, eg 6 mm, is a measure of the distance across the flats of the hexagon.

It is important that the key is the correct size. Using a key which is a loose fit will damage both the key and the hole in the socket screw.
Gripping and clamping tools

Standard pliers
Pliers are gripping tools mostly used to hold small components which would otherwise be difficult to grasp and control. Pliers are also used for shaping and bending light sheet metal as well as bending, twisting and cutting small diameter wires.

Diagonal cutting pliers
Another name for diagonal cutting pliers is side cutters. These pliers are made with the jaws cranked, or offset, that is; they are set at an angle which allows wire to be cut close to a surface or in confined spaces. They are also available with insulated handles for electrical work.

Photographs BOC Limited ©2006

Fig 2.59 – (a) Standard pliers, and (b) diagonal cutting pliers
The most common of these are multi-grip pliers. When they are used as light pipe wrenches, they are known as gas fitters’ pliers. Slip joint, multi-grip pliers have a shaped pivot pin, which can fit into two or more openings in the legs. This gives a range of jaw openings that allow parallel gripping by the jaws in a number of positions. Multi-grips are useful for holding and controlling small components and bending light gauge parts.

**WARNING:**
Short ends of wire, particularly steel wire, are liable to fly when cut. Guard against this. Cut with the free end of the wire pointing away from you. Wear goggles if necessary.

Never cut electrical wires unless you are sure the power has been disconnected first.
Types of clamping devices

Clamping tools are in common use in the metal fabrication workshop. Each clamp has a variety of uses and may be used to hold or align materials in position ready for welding, riveting or screwing. They may also be used to help reduce welding distortion.

G clamps

The G clamp is made from either malleable cast iron or has its main body forged from high quality steel. A screw thread is fitted to one end to apply force, and this employs a swivelling cap to prevent marking of the surface of the material. G clamps are available in a variety of sizes ranging from 50 mm to about 300 mm capacity. The major disadvantage of the G clamp is that it is slow to adjust over large variations in clamping distances.

WARNING:

Do not increase the pressure between the jaws by applying a greater leverage than the clamp is designed to take, as this will distort or damage the clamp.
F clamps
F clamps (or quick action bar clamps) are able to be quickly adjusted to suit various applications. The threaded adjustable jaw is slid along a marked bar to adjust to a thickness. When the clamping thread is tightened, the jaw locks into position on the bar by a combination of jamming and friction forces.

![Fig 2.62 – F clamps](image)

Sash clamps
The jaws of the sash clamp are fitted to a long bar or sash. One of the jaws can be moved along the sash bar by removing the locking pin, setting the size and then replacing the locking pin. The clamping section of the sash clamp is fixed to the other end but threaded to allow clamping force to be applied to the other jaw. The big advantage of the sash clamp is that it can be quickly applied to a wide range of distances.

Sash clamps are available in many lengths and can be made to any desired size to suit the particular needs of a specific job.

![Fig 2.63 – Sash clamp](image)
Chapter 2 – Tools of the trade (hand)

**Toggle clamps**

Toggle clamps are simple, quick acting and adjustable over centre devices that may be bolted to a bench to allow for fast clamping action.

![Fig 2.64 – Toggle clamp](image)

**Spring clamps**

These simple hand spring clamps have two flat jaws that are forced together by a strong spring. When the handles are pressed together, the jaws open. On releasing the handles, the spring once again forces the jaws to close.

![Fig 2.65 – Spring clamps](image)
Self-locking grips
A wide variety of self-locking pliers or vice grips is available. The size and shape of each type is different but the adjusting operation for each is the same.

Self-locking pliers
Self-locking pliers are available with straight jaws or curved jaws. Both types have serrations on the inside to allow them to grip an object. Self-locking grips can be used as pliers as well as for clamping.

Self-locking welding grips
Self-locking welding grips are used for clamping panels, pipes or bar stock together. The jaws are designed to allow access during the welding process.
Flat nose self-locking grips

Flat nose self-locking grips have broad flat jaws for holding metals together for drilling or spot welding. Another use is to bend light material to a desired shape or angle.

D clamp self-locking grips

D clamp self-locking grips have two hinged arms with a handle at one end and, at the other, curved bevelled jaws that close on the work piece. This shape allows access to odd or irregularly shaped objects.
Chapter 3 – Tools of the trade (power)

Introduction

The metal fabrication tradesperson has a range of hand held power tools at their disposal, and they are required to have knowledge of and be able to use these power tools.

In this chapter we will look at the following.

- Tools of the trade (power)
  - drills and drilling machines
  - grinding and grinding machines
  - bevelling machines
  - jig saws/sabre saw.
Drills and drilling machines

Hand held power tools fall basically into three groups:

- battery powered (cordless)
- compressed air powered
- electrically powered.

Battery powered (cordless) hand tools

While cordless power tools are in common use in the building industry, they are not yet in common use in the metal fabrication industry. The loading on power tools used in the fabrication industry is high, and batteries are quickly flattened. Therefore, apart from some site work applications, cordless power tools are not yet in wide use.

Photograph BOC Limited ©2006

Fig 3.1 – Battery powered drill
Compressed air powered hand tools
Compressed air powered tools are simple, reliable and hard working. They are able to perform similar functions to the electrical powered hand tools listed next.

(a) (b)

Photographs BOC Limited ©2006

Fig 3.2 – Examples of compressed air powered hand tools (a) drill, and (b) disc sander

Electrically powered hand tools
The powered hand tools most commonly used in the general fabrication industry are:

- electric drills
- angle grinders
- straight grinders
- disc sanders.

Photograph BOC Limited ©2006

Fig 3.3 – Electric powered disc grinder
In addition to these, the aluminium fabrication industry employs the use of powered hand tools such as:

- planes
- routers
- saws – circular, jig saw, sabre saws.

**Electrical extension leads**

Extension leads used in conjunction with power tools should have sufficient capacity to deliver the required current. In every metre of lead, a small voltage drop occurs, due to electrical resistance. Similarly, leads of insufficient cross-sectional area reduce current flow and generate heat. Leads that are excessively long or light cause a reduction in the current available to the tool.

Recommended leads are as follows.

<table>
<thead>
<tr>
<th>Length of lead</th>
<th>0 – 3.4 AA</th>
<th>3.5 – 5 A</th>
<th>5.1 – 7 A</th>
<th>7.1 – 2 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 m</td>
<td>7.5 A</td>
<td>10 A</td>
<td>10 A</td>
<td>15 A</td>
</tr>
<tr>
<td>30 m</td>
<td>10 A</td>
<td>10 A</td>
<td>15 A</td>
<td>15 A</td>
</tr>
<tr>
<td>60 m</td>
<td>15 A</td>
<td>15 A</td>
<td>15 A</td>
<td>20 A</td>
</tr>
<tr>
<td>90 m</td>
<td>15 A</td>
<td>15 A</td>
<td>20 A</td>
<td>30 A</td>
</tr>
</tbody>
</table>

**Electrical safety**

It must be kept in mind when using electric power tools that the potential for a harmful or possibly fatal electric shock always exists. To minimise the chance of electric shock, the following electrical safety precautions should be followed.

**Prior to use**

- Visually examine all leads and plugs for signs of damage or wear and signs of frayed insulation.
- Ensure that all leads and extension leads are tagged and dated correctly.
- Ensure that all connections are positive and tight. Ideally, weatherproof plug and socket connections should be used as the screwed connection prevents separation of the plugged connection.
- Select extension leads that are as short as practicable and of the rated capacity.
- Ideally, protection devices such as earth leakage devices and isolating transformers should be used.
- Ensure that tools, leads and hands are dry.
During use
- Leads that are coiled or wound on drums or reels should be unwound completely. Coiled leads build up magnetic fields that may cause overheating and a loss of current.
- Leads running across traffic areas should be protected from damage.
- Do not overload the tool by selecting a tool that is too light for the job, or by using excessive pressure. Stop using any power tool that shows signs of overheating. Apart from variable speed tools, the motor should run at full speed. The sound of the motor slowing or smoke appearing, indicates that the tool is overloaded.
- Always disconnect the power lead before carrying out any maintenance.

General safety and operation
- Allow the tool to reach maximum RPM before commencing work. This will avoid overloading.
- Always make sure that grinders, drills, etc have completely stopped prior to putting them down.
- Keep drills, blades etc sharp, as this speeds up the operation and avoids overloading the tool.
- Ensure that you have a firm grip on any tool prior to operation and are well balanced.
- Ensure that all guards and handles are firmly in place and correctly positioned.
- Never suspend a power tool by the lead. Use a hauling line when working from scaffolds etc to raise and lower tools.
- Keep the work area clean. Avoid a build up of swarf, rags and combustible material.

| swarf | the debris or waste resulting from metalworking operations |

- Wear all necessary protective clothing and eye protection. Ensure that cuffs and pockets are securely fastened and free from frays and tears.
- Avoid using the trigger-locking pin of tools that are being operated by hand.
- Ensure that leads are away from the tool when in operation so that they cannot be cut.
Most modern power tools are rated on the label in terms of the wattage they consume. The label is a general guide as to the power the tool is able to produce. For example, a typical domestic drill may be rated at 400 watts – this indicates it is fairly weak and in reality can only be used for light duty. An industrial drill or small angle grinder may be rated at 600 watts.

Any appliance rated at over 750 watts should be treated with caution. A large drill or angle grinder may be rated at over 2000 watts, which is the equivalent of three horsepower.

**Maintenance of electrically powered tools**

Power tools may be:

- single insulated
- double insulated
- all insulated.

**Fig 3.4 – Double insulated symbol**

Do not tamper with, connect or disconnect the earthing lead of any power tool. All electrical maintenance should be carried out by a qualified electrician.

- Keep tools clean and dry. Tools should be wiped clean periodically.
- Keep any cooling vents clear.
- Have an electrician inspect and replace motor brushes at regular intervals.
- Avoid excessive lubrication. Some tools require no lubrication during their life.
- Clearly label all damaged or faulty equipment.
Drills and drilling

Portable electric drills

In the metal fabrication industry, hand-held electric powered drills are used for drilling small holes only (up to 10 to 12 mm). They are commonly used for light duty, jobbing work, or for site work. Wherever practical, fixed drilling machines such as bench, pedestal or radial arm drills are used. These drills are more suited to the fabrication industry as in general, high feed pressures and relatively powerful motors are required to drill metals, particularly as the hole diameter increases.

Hand held electrical drills may be:

- single speed – usually high speed for drilling small diameter holes
- dual speed – can be used for drilling a variety of materials with various drill capacities
- variable speed – enabling the operator to select the optimum speed for the drill size and material being drilled
- impact drills – for drilling masonry.

Additionally, drills may be fitted with a clutch mechanism. This enables screws etc to be tightened to the correct torque and also acts as a safety mechanism should the drill bit jam.

Operation and safety

The following basic safety rules should always be followed when using an electric powered drill.

- Wear safety glasses when drilling any material.
- Use the side handle when the drill diameter exceeds 8 mm.
- Secure the work piece against rotation. These precautions will prevent injury to the operator should the bit jam and tend to rotate the machine or work. Some drills have safety clutches to help prevent this back torque problem.

Never use a drill from a ladder. Back torque may result in the operator being dislodged from the ladder. Always adopt a balanced stance.
Chapter 3 – Tools of the trade (power)

To operate the drill, proceed as follows.

1. **Select the drill bit.** Carbon steel drill bits are used for wood and soft steel. High-speed steel drill bits are used for general engineering applications. Carbide tipped bits are used for stone, concrete, brickwork, ceramic tile, asbestos cement. These require slow rotational speed and high feed pressure.

2. **Insert the drill bit.** Most drills have a three jaw, key tightened chuck. Hand tighten the bit, and then tighten with the key. For drilling that requires many drill changes, a keyless chuck is desirable. This is tightened by hand pressure.

3. **Select and set the correct speed.** Usually the smaller the bit, the higher the speed required. Usually the harder the material, the slower the speed required. With variable speed drills, experiment to find the optimum speed. Centre punch the hole to be drilled.

4. **Secure the work.** Use a vice if possible. Place the drill bit point on the drilling mark. Hold the bit in firm contact with the work. Hold the drill at the correct angle.

5. **Switch on the drill and drill the hole.** Firm pressure is required for hard materials. Hold the drill steady. Keep the machine switched on until the drill is withdrawn from the work. This will clear the waste from the holes.

Do not operate the drill for protracted periods at slow speed with large bits. The low fan speed will cause the drill to overheat. Keep hands away from vent holes to allow a free airflow.

Mount the drill in a drill stand if possible when drilling steel. This enables greater accuracy, pressure control, and alignment.

**Magnetic drilling machines**

The term magnetic drill refers to the method the drill uses stand to attach itself to the component being drilled, see Fig 3.6. The drill, although being portable, is usually a heavy duty machine.

![Photograph BOC Limited ©2006](Fig 3.6 – Magnetic drill stand)
Bench drill press

The bench drill press, as its name implies, is made to be placed onto or bolted to a bench. The bench press is generally more powerful than hand held machines and has chuck capacity of 12 to 15 mm.

![Bench drill press](image)

Photograph BOC Limited ©2006

Fig 3.7 – Column drill

Straight or parallel shank drill

This type of drill is made from high speed steel and can be run at faster speeds than ordinary carbon steel drills. They can be used with hand or portable drilling machines, as well as the fixed machines.

Straight shank drills are held in a drill chuck (see Fig 3.8), which grips the shank between three self centring jaws. The jaws are opened or closed by rotating the knurled or grooved outer ring and a key is provided for the final tightening. The chuck may be screwed to the machine spindle, but more generally they are fitted with a taper shank which locates in the taper bore of the spindle.
It is necessary for a drill to be properly ground if a good quality hole is to be produced and unnecessary wear to, or breakage of, the drill is to be avoided.

**Points to observe**

The point is ground to an included angle of 118° (Fig 3.9). This angle is suitable for most purposes and on standard drills results in the cutting edge of the drill being straight. Angles greater than 118° (125° to 140°) are used for metals difficult to drill, such as steel forging, and alloy steels.

Angles less than 118° (90° to 100°) are used for ease of penetration when drilling brass, soft cast iron, and the light alloys (aluminium etc).
Equipment to clamp and hold work for drilling

The cutting action when drilling tends to cause the work to rotate with the drill. As this could cause injury to the operator, and damage to the drill and the work, steps should be taken to prevent movement.

In some cases the use of one or more stops to prevent rotation is sufficient (Fig 3.10). Very small holes or large heavy pieces of work are often drilled in this manner, the work being held down by hand or by its own mass. In other cases, the work must be clamped.

Fig 3.10 – Prevention of rotation

Fig 3.11 – Gripping the work in a machine vice
Grinding and grinding machines

Angle grinder

The angle grinder is in common use in the fabrication industry, particularly for the fabrication and clean up of steel products. The angle grinder provides a convenient and efficient means of slag and scale removal and final finishing or shaping to accurate dimensions.

The angle grinder is so called because the disc rotates at right angles to the electric motor.

Photograph BOC Limited ©2006

Fig 3.12 – 230 mm (9 inch) right angle grinder

The angle grinder employs the use of a hard (and usually recessed) grinding disc. This disc is covered by a guard or safety shield, which must be kept in place at all times. A range of grinding discs is available for grinding materials such as carbon steel, stainless steel, and aluminium.

Choice of the correct disc suited to the grinder RPM and material being ground is important as material contamination, or clogging of the disc, may result if the incorrect disc is chosen. Manufacturers’ recommendations should be followed in this regard.

Grinders come in a range of sizes from 100 mm (wheel diameter) up to 230 mm. It is important to select the correct size grinder for the job. 100 mm and 125 mm grinders are suitable for light work only, and are easily overloaded. Larger grinders have more power and provide faster and more efficient removal of metal. 180 mm and 230 mm grinders are powerful tools, and the operator will not be able to stop the wheel or hang on to the grinder should the disc jam due to inappropriate use. A firm grip of both handles of the grinder is essential and its use should be in line with recommended procedures.

Cut-off wheels are available for use with angle grinders. These discs are thinner than a grinding disc and do not have a recessed centre, and are liable to flex and shatter if used incorrectly. Cutting discs should only be used to cut light gauge materials and if at all possible, cutting should be carried out by other means such as a drop saw, for example. Once again it is essential that both handles are gripped firmly, guards are in place, and the machine is used in line with manufacturers’ recommendations.
Types of discs
Reinforced cutting-off discs have layers of glass fibres bonded into the wheel to give greater strength, flexibility and safety. The use of these discs provides fast economical cutting of steel bars, tubing and plate.

The selection of the current abrasive type is very important.
- Aluminium oxide is for use on ferrous and non-ferrous metals.
- Silicon carbide is for use on ceramics, masonry and other non-metallic materials such as concrete and bricks.

Depressed centre discs
Depressed centre discs are designed with reinforcement for use on right angle portable grinders where side pressure is involved. They have an adequate safety factor even for the most rugged operations. They are much thicker than the cutting-off wheel.

Aluminium oxide discs are used on the grinding of all steels and annealed malleable cast iron. Silicon carbide discs are recommended for grinding cast iron, aluminium and other non-ferrous metals.

Bendum type discs
Bendum type discs are flexible discs used for blending, smoothing and polishing steels and non-ferrous metals such as cast iron and brass aluminium, as well as non-metallic such as plastics.

Straight grinder
The straight grinder (or barrel grinder as it is commonly called) is used for numerous grinding applications. It is ideal for grinding narrow areas, such as when weld reinforcement needs to be ground flat, or for the removal of scale alongside welds, particularly inside pipes. As with all grinders, it is important to hold the machine firmly.

Movement of the straight grinder should be backwards, against the direction of rolling where possible, as this will reduce the tendency of the straight grinder to run with the rotation of the wheel.

As with all portable grinders, they should be allowed to stop before putting them down. This is particularly important with straight grinders, even if care is taken to put them down with the wheel clear of the bench. Centrifugal force of the motor can cause the body of the grinder to rotate, and it could fall or wrap up the lead.
Disc Sanders

Disc Sanders are available either as a straight, or in-line type, or as an angled sander – which is the type most commonly used in the fabrication industry. Sanders are ideal for surface finishing, particularly where smooth, rounded corners are required. They are particularly useful in the aluminium industry, where they are used for removal of surface oxide prior to welding, or for cleaning up and final polishing.

Sanders employ the use of a flexible abrasive disc supported by a rubber or fibre back-up pad. The discs are held in position by a broad, flat, locknut, which fits into a depression in the centre of the pad. Alternatively the disc may self-adhere to the pad.

Sanders operate at lower RPM than grinders. This minimises clogging of the disc and burning of the surface being sanded.

To use a disc sander, proceed as follows.

1. Grip the machine with both hands.
2. Adopt a well-balanced position and do not over-reach.
3. Start the machine and allow it to reach full speed.
4. Tilt the handle slightly and bring the front section of the disc in contact with the work.

This technique makes control easier, as the disc pulls in one direction only. Burning of the work and clogging of the abrasive sheet is reduced, as only a portion of the disc is in contact with the work.
Safety
Before commencing grinding operations ensure that you are safely dressed.

1. No loose sleeves, or flapping ties.
2. Close fitting overalls buttoned to the neck should be worn.
3. Safety glasses must be worn under a clear full-face safety shield.
4. Leather apron should be worn.
5. Safety boots should be worn.

Leather gloves should not be worn during grinding operations.

During grinding operations
Consider the following points when using the angle grinder.

1. Stand comfortably supported evenly on both feet.
2. Position yourself so that grinder pressure can be applied to the work safely.
3. Make sure grinder power leads are well clear of grinding operation.
4. Ensure that grinding discs are replaced when worn to within 25 mm of top fixing flange.
5. Check for damage to grinding discs before grinding commences.
6. During grinding operation, damaged grinding discs will cause severe machine vibration and erratic operation.
7. Portable electrical grinders should be used with an Earth Leakage Circuit Breaker (ELCB) to reduce the risk of electrical shock.
Safe use of sanders and grinders

- Inspect and ensure electrical safety.
- Ensure guards are correctly and securely fitted.
- Inspect the disc/wheel for any signs of damage and ensure that it is tightly fitted.
- Ensure you are well balanced.
- Grip the grinder securely with both hands.
- Eye protection must be worn.
- Hearing protection must be worn.
- Ensure no fire hazard exists from flying sparks.
- Direct sparks away from others and towards a safe place.
- Stop the wheel before putting the grinder down.
- Ensure the grinder cannot fall.

Bench type grinder

Bench grinders (Fig 3.15) may be fitted directly on to a bench. Abrasive wheels are fitted directly to each end of the motor spindle. Usually a coarse grit wheel for roughing and a fine grit wheel for finishing are mounted on each end of the spindle. In the metal fabrication workshop, bench grinders are usually reserved for tool sharpening.

Plate beveller (nibbler)

Plates above 6 mm in thickness that are to be joined by butt welding will generally require weld preparation to be applied to the plate edges. Applying preparation with the plate beveller (or ‘nibbler’ as it is more commonly called) is a simple and versatile method of doing this. This electrically operated machine can be used to apply single or double vee preparation to a range of ferrous and non-ferrous materials.

The machine is available in two sizes. The smaller is suitable for bevelling plates up to 25 mm thick, and the larger is suitable for plates up to 32 mm thick.

In both cases the machines are fully portable, and may be used to prepare edges that are straight or have either convex or concave curves. For concave curves, the smallest radius that can be bevelled is approximately 40 mm.
Fig 3.16 – Plate beveller fixed mounting

Fig 3.17 – Plate beveller with balancer attached
Fig 3.18 – Manually held curve

The nibbler may also be used for bevelling on tubes and rings of small or large diameter.

Fig 3.19 – Pipe bevelling

The nibbler is capable of preparing bevelled edges to angles of 30°, 37.5°, or 45°. By changing the guide bracket, it is also possible to produce angles of between approximately 15° and 55°. A feature of the bevelling machine is that bevelling may be started and stopped at any point of the edge being bevelled.
Blade action
The blade of the nibbler moves in a reciprocating action (Fig 3.21).
Safety
When operating a bevelling machine, ensure the following:

- safety glasses are worn
- loose clothing is tied back
- a container is used to collect metal chips
- a firm grip is taken before starting the machine
- a balanced stance is adopted
- the blade is correctly adjusted
- metal is not forced into the machine.

Jig saw/sabre saw

The jig saw and sabre saws are reciprocating saws. They range from simple light duty single speed models, to heavy duty variable speed models with a range of sophisticated features. Most saws cut on the up-stroke, so that the cutting action pulls the saw and the work piece together. This makes cutting easier, and minimises vibration.

Cutting action

Cutting is done on the up-stroke only. Some jig saws have a reciprocating (up and down) action only. Some have an oscillating (oval) action, which is useful for cutting steel and other hard materials. The oscillating action lessens blade drag. Some saws have the blade canted forward at the bottom to give clearance on the down-stroke. Others have an adjustable roller support to lessen the unsupported length of the blade.
Some manufacturers produce sabre saw blades that will cut on the down-stroke.

**Fig 3.23 – Reciprocating action of jigsaws**

**Operation**

- Select the appropriate saw blade. Discard worn or damaged blades. Many different blades are available for various materials. For scroll or tightly curved work, narrow blades are necessary.
- Use a lubricant when cutting metal. If teeth become clogged in soft metal, use a coarser blade. If blade chatters excessively, use a firmer blade. Bees wax will reduce clogging of the teeth when cutting soft metals such as aluminium.
- Set the saw to the correct speed. Generally, use high speed for cutting soft materials such as timber, plywood, soft metal, and some plastics. Use low speed for hard, dense, materials such as steel. On variable speed models, adjust the speed dependant on the rate of feed, hardness and thickness of material.
Chapter 3 – Tools of the trade (power)

Fig 3.24 – Saw blades

Use of jig saws

- Place the front of the base plate on the work before switching on the jig saw.
- Switch on the saw.
- Allow the saw to gain full speed before starting the cut.
- Start the cut. Never force the saw, use firm pressure. Keep the base plate in firm contact with the work. Very thin material should be sandwiched between two layers of timber.
- Allow the saw to stop before removing it from the work. Wherever possible, drill a hole for starting internal cut-outs. Never exceed the capacity of the saw.
When any air powered tool is issued it should be checked. Does the air tool run properly and has it been lubricated prior to use? Are the connections secure, is there any damage or fraying or leaks on the supply hose?

Electrical extension cords should be inspected and tested regularly, and should be tagged to show the date of last compliance. Electrical power tools should be inspected for damaged supply cords and connections. Power tools should be free-run tested for any rough running.

Any power tool that is not one hundred per cent functioning should be taken out of service and tagged with an out of service or danger tag.

Only authorised personnel are allowed to remove a tag on a power tool.

ELCB equipment have electrical safety devices that will disconnect electrical supply current in the event of power leads becoming damaged, or if current passes through the operator.

ELCB plug in portable units are available if ELCB protection is not inbuilt to the electrical switchboard.
Chapter 4 – Job planning

Despite the many classifications within the metal fabrication trade, such as light fabricators who work on materials up to 3 mm, or heavy fabricators who work on 3 mm and above, the base skills of the typical tradesperson remain the same as those required and developed by our pioneers during the industrial revolution.

The typical metal fabrication tradesperson is still required to read drawings, job plan and calculate material size and mass. They may mark out on material or develop patterns. The fabricator may use hand tools, power tools or machinery. They may cut materials, form up, assemble and join parts.

These tasks are always carried out in the same logical sequence, because it would be impossible for example to complete the assembly without knowing what is required.

In this chapter we will look at the following.

- Job planning
  - job plan
    - simple job plan
    - complex job plan
    - production sequence
  - steel products and their uses
    - determining the nominal size of rolled steel products
    - tolerances for rolled steel sections
    - calculating mass.

Job plan

A job plan is a prescribed sequence of tasks or events that should be performed in order to complete a required job. A job plan is not usually required by an experienced tradesperson, because they have learnt the processes involved and this has almost become second nature to them. The study of job plans can, however, be very useful to students developing these skills. The job plan process can be very simple, or made very complex.
Simple job plan
A simple job plan for the fabrication of a component or structure would be as follows.

1. Read drawing/s.
2. Make up material list and locate material.
3. Mark out components.
5. Perform machining or forming operations.
6. Assemble parts or components.
7. Weld together.
8. Check assembly.

These simple basic steps can be shown on a chart, and can also be further broken down into smaller sub groups that show more detail. Each of the sub groups could also be broken down into further tasks, if required.

<table>
<thead>
<tr>
<th></th>
<th>Read drawings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Read and understand drawings.</td>
</tr>
<tr>
<td></td>
<td>List equipment and tools required.</td>
</tr>
<tr>
<td></td>
<td>Make up material list</td>
</tr>
<tr>
<td></td>
<td>Decide quantities, check handling etc.</td>
</tr>
<tr>
<td></td>
<td>May involve seeking out alternative materials (actual sections may not be available) or making out a more comprehensive cutting list.</td>
</tr>
<tr>
<td></td>
<td>Mark out components</td>
</tr>
<tr>
<td></td>
<td>How much time and space is required?</td>
</tr>
<tr>
<td></td>
<td>What tools are required?</td>
</tr>
<tr>
<td></td>
<td>What production sequence is required?</td>
</tr>
<tr>
<td></td>
<td>Cut components</td>
</tr>
<tr>
<td></td>
<td>What tools are required?</td>
</tr>
<tr>
<td></td>
<td>Methods to use, safety.</td>
</tr>
<tr>
<td></td>
<td>Equipment required, availability, special precautions.</td>
</tr>
<tr>
<td></td>
<td>Machining and forming</td>
</tr>
<tr>
<td></td>
<td>May involve drilling, punching, grinding.</td>
</tr>
<tr>
<td></td>
<td>Forming by rolling and pressing.</td>
</tr>
<tr>
<td></td>
<td>Assembly</td>
</tr>
<tr>
<td></td>
<td>Equipment required.</td>
</tr>
<tr>
<td></td>
<td>Special techniques.</td>
</tr>
<tr>
<td></td>
<td>Welding</td>
</tr>
<tr>
<td></td>
<td>Equipment required, availability, special precautions required.</td>
</tr>
<tr>
<td></td>
<td>Correct consumables, preheat, techniques etc.</td>
</tr>
<tr>
<td></td>
<td>Checking</td>
</tr>
<tr>
<td></td>
<td>Extent of checking, tolerances, methods.</td>
</tr>
</tbody>
</table>

Table 4.1 – Simple top-down job plan
These sequences or tasks can also be applied to a different type of graphic plan, such as the table shown below.

- Divide the whole task into basic steps.
- For each basic step, list smaller steps.

<table>
<thead>
<tr>
<th>Drawings</th>
<th>Materials</th>
<th>Marking</th>
<th>Cutting</th>
<th>Forming</th>
<th>Assembly</th>
<th>Welding</th>
<th>Check</th>
</tr>
</thead>
<tbody>
<tr>
<td>interpret</td>
<td>material list</td>
<td>tools required</td>
<td>method</td>
<td>equipment</td>
<td>bench space</td>
<td>process</td>
<td>specs standard</td>
</tr>
<tr>
<td>check dimension</td>
<td>available</td>
<td>methods</td>
<td>process equipment</td>
<td>settings</td>
<td>lifting gear</td>
<td>weld preparation</td>
<td>tools</td>
</tr>
<tr>
<td>problem solve</td>
<td>order</td>
<td>checking</td>
<td>available</td>
<td>methods</td>
<td>equipment</td>
<td>settings</td>
<td>pass/fail</td>
</tr>
<tr>
<td>time line</td>
<td>storage</td>
<td>settings</td>
<td>methods</td>
<td>tacking welding</td>
<td>cleaning</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 4.2 – Table for planning**

A metal fabricator may not be required to perform many of the functions described within a complex job plan, as these may be performed by highly skilled personnel such as engineers, welding supervisors or inspectors.

**Complex job plan**

A complex job plan is required where quality assurance is to be provided, such as that required in standards such as the structural steel welding code or boiler and pressure vessel codes such as AS/NZS 1796:2001. Quality control at various stages is required in most standards or codes, and the sequence shown below is typical. Check:

- design and drawings
- materials
- personnel
- equipment
- cutting
- forming and assembly
- tacking and welding
- completion and testing.

A list of over thirty items may be used, depending on the complexity of the job.
Time line charts

A job plan can also be applied to a time line chart that shows expected completion time of each stage as required. A simple time line chart for a boiler is shown below in Table 4.3.

<table>
<thead>
<tr>
<th></th>
<th>Design</th>
<th>Drawing</th>
<th>Cutting</th>
<th>Assembly</th>
<th>Tacking</th>
<th>Welding</th>
<th>Testing</th>
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</thead>
<tbody>
<tr>
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<td>February</td>
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<td>■ ■ ■</td>
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<td>March</td>
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<td>April</td>
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</table>

**Table 4.3 – Time line chart**

Production sequence

A production sequence is a series of instructions or markings that describes the operations to be performed on a component or part prior to final assembly. A production sequence may seem unnecessary, but in some workshops the tradesperson may be required to perform only one task, such as marking out. Semi-skilled workers may be used for some operations, or work may be carried out at a later time.

A simple production sequence may be a plate marked with centre lines, bend lines and hole sizes.

![Fig 4.1 – Production sequence for plate mark up](image-url)
A plate that is to be pressed and rolled may have preset and rolling direction, and instructions for cutting on it.

Fig 4.2 – Production sequence for plate pressing/rolling
Steel products and their uses

Plate

Plate is used for base plates, connectors, stiffeners, gussets and cleats.

<table>
<thead>
<tr>
<th>Plate Specifications</th>
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**Fig 4.3 – Plate**

<table>
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<th>Component</th>
<th>Description</th>
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<tr>
<td>cleats</td>
<td>used to make connections between various components</td>
</tr>
<tr>
<td>gussets</td>
<td>used to prevent movement, or reinforce parts</td>
</tr>
<tr>
<td>stiffeners</td>
<td>act to prevent any movement in parts of a structure</td>
</tr>
<tr>
<td>strut</td>
<td>are members that are used in compression</td>
</tr>
<tr>
<td>tie</td>
<td>used to restrict movement and are usually in tension</td>
</tr>
</tbody>
</table>

**Flat bar**

Flat bar is able to be bent easily in one plane and is not used in compression. It can be used in tension as a tie, more often used for stiffeners, connectors, and cleats.

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**Fig 4.4 – Flat bar**
Equal angle and unequal angle

Angle iron is able to resist bending in both planes, and can be used in compression and tension. Angle can be used as a column, strut or tie, and is also used for stiffeners, connectors, and cleats.

Fig 4.5 – Australian Standard® angle

Fig 4.6 – Australian Standard® unequal angle

Circular hollow section

Fig 4.7 – Circular hollow section
Square hollow section and rectangular hollow section

Hollow sections are able to resist bending in both planes and can be used in compression members such as columns or struts. Hollow sections can also be used to span distances, and as beams or supports, or as members in fabricated trusses or structures.

**Fig 4.8 – Square hollow section**

**Fig 4.9 – Rectangular hollow section**
Parallel flange channel

Steel channels offer increased resistance to compression and bending forces over other members. They can be used in compression as a column or support and for spanning distances such as in purlins or floor beams.

![Diagram of Parallel Flange Channel](image)

**Fig 4.10 – Parallel flange channel**

| purlins | horizontal members that connect roof or wall material to rafters or columns |

Universal columns

Universal columns have a large cross section that gives good resistance to bending when used in compression and they are most commonly used for vertical supports such as columns or stanchions.

![Diagram of Universal Column](image)

**Fig 4.11 – Universal column**
Universal beams

Universal beams have a large depth-to-width ratio that improves resistance to bending across the centre web. Used for supporting a load over a large distance. Typical uses are floor beams, crane beams, bridge supports etc.

Fig 4.12 – Universal beams

Tapered flange beams

Tapered flange beams are similar in shape to universal beams, except for the tapered shape of the flanges, and are often used for the same applications. The tapered flanges require the use of tapered washers when they are to be bolted to other members.

Fig 4.13 – Tapered flange beams
Determining the nominal size of rolled steel products

Nominal size
This is the size given to the section by the manufacturer and is shown on drawings and given when ordering material. Nominal sizes, and other data, are provided by the manufacturer. Reference should be made to the manufacturer’s data sheets to find the relevant information. Extracts from the OneSteel product information brochure are included on the following pages for your reference. For example, refer to the extract of the resource material as given below to establish the depth of section of a 200UB 18.2.

![Diagram of rolled steel section]

Eg 200 UB 18.2

Fig 4.14 – Beam

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<th>Depth of section</th>
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Table 4.4 – Sample steel specification sheet

Note how the depth of section, flange width, and other key dimensions vary with the change in section mass per metre.

Tolerances for rolled steel sections
As sections are rolled to shape from red hot steel, their finished size may vary by several millimetres. A certain tolerance is allowed when these products are formed in the mill. This is the reason for variations in nominal size and squareness in the finished products.

Variation in size may also be caused by machining tolerance, machine set up or subsequent wear on the rolls. This difference in size between sections is called manufacturing or rolling tolerance. It is allowed for and limited by the requirements of Australian Standard® AS/NZS 3678 and AS 3679 which sets two sizes for structural sections.
Chapter 4 – Job planning

Manufacturing tolerance
This is the acceptable variation from any nominal size. Variation can occur in thickness, depth, width, or angle of flange or web.

Manufacturing tolerances can be in:
- the mass (kg per metre)
- thickness of various parts
- size of webs and flanges
- out of squareness
- off centre
- twisting
- straightness.

When working with rolled steel sections, you must measure the material you are using to find out if there is any difference between the actual and nominal size, so that allowances can be made before marking out and fabrication.

Calculations mass
It is often necessary to know the mass of individual structural steel components for the purpose of selecting lifting gear, or for transport and storage arrangements. Often the mass of a component or structure needs to be known so that an estimator can fix a price for a quotation. Steel is often purchased on a tonne rate, and stores may need to know the mass for purchase orders and costing.

The mass of a structural member can be easily worked out by using calculations utilising any one of the three following methods:
- from the designation
- from figures found in tables or charts
- by finding the volume of the material and using the density value for steel of 7850 kg/m³.
Mass example using designation

Example 1
Find the mass of a steel column 14 metres long of 200 UC 52.2.

\[
\text{mass} = \frac{\text{kg/m}}{\text{length (metres)}}
\]

\[
\text{mass} = (\text{from designation}) \times 52.2 \times 14
\]

\[
\text{mass} = 730.8 \text{ kg}
\]

Example 2
Calculate the mass of a 6 metre 360 UB 50.7 beam.

\[
\text{mass} = \frac{\text{kg/m}}{\text{length (metres)}}
\]

\[
\text{mass} = (\text{from designation}) \times 50.7 \times 6
\]

\[
\text{mass} = 304.2 \text{ kg}
\]

Mass example using tables or charts

Example 1
Find the mass of a steel angle 6 metres long of 45 x 45 x 6.

\[
\text{mass} = \frac{\text{kg/m}}{\text{length (metres)}}
\]

\[
\text{mass} = (\text{from OneSteel table}) \times 3.97 \times 6
\]

\[
\text{mass} = 23.82 \text{ kg}
\]

Example 2
What is the mass of a bundle of 10 only 4.3 metre lengths of 100 x 100 x 10 ASA.

\[
\text{mass} = \frac{\text{kg/m}}{\text{length (metres)}}
\]

\[
\text{mass} = (\text{from OneSteel table}) \times 14.2 \times 10 \times 4.3
\]

\[
\text{mass} = 610.6 \text{ kg}
\]

Mass example using volume (m³) x density of steel

Example 1
Find the mass of a steel plate 2400 long x 1200 wide x 20 thick.

\[
\text{mass} = \text{volume (m}^3\text{)} \times \text{density}
\]

\[
\text{mass} = (\text{L x B x H}) \times \text{density}
\]

\[
\text{mass} = (2.4 \times 1.2 \times 0.020) \times 7850 \text{ (kg/m}^3\text{)}
\]

\[
\text{mass} = 452.16 \text{ kg}
\]
### Universal Beam – Properties and Dimensions

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# Universal Column – Properties and Dimensions

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# Parallel Flange Channel Properties and Dimensions

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Range includes 123, 100 and 75 PFC.
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## EXTRACT FROM ONESTEEL HOT ROLLED AND STRUCTURAL STEEL PRODUCTS

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Chapter 5 – Mechanical cutting

Cutting material is an essential part of the fabrication industry and a wide variety of methods are used. Mechanical cutting methods (sometimes referred to as cold cutting) have considerable advantages over thermal cutting in terms of ease of operations and productivity. Heavy duty drilling and heavy duty grinding are also included in this chapter.

In this chapter we will look at the following.

- Mechanical cutting
  - shearing
    - safety
  - the universal plate worker
    - safety
  - sheared edges
  - saws and sawing
  - drilling machines
    - stationary machines
  - grinding machines
    - stationary grinding machines.
Shearing

Shearing is a process that literally tears the material apart through force.

Manual shearing methods are mainly used to cut small sections of flat bar stock or small plates up to 3 mm maximum. Manual shearing machines use an action that is similar to a scissor movement and the force required is provided by a mechanical multiplier.

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Guillotine

This is a mechanical process for cutting sheet metal, plate and flat bar. Small capacity sheet metal guillotines may be operated manually by hand or by foot.

Photographs courtesy of Fiora Machinery

Fig 5.2 – (a) Foot operated guillotine, and (b) power driven guillotine
Most heavy duty guillotine machines are electro mechanical or hydraulically operated. Most guillotines have two blades, the lower being fixed and horizontal, the upper blade being movable vertically, and inclined with a rake angle towards one end which gives a similar action to hand shears but the blade is kept closer to being parallel.

Each cut is completed in one downward stroke and if the machine is set up correctly there is virtually no distortion of the off cut. Blades may be up to five metres in length and capable of guillotining 18 mm thick steel depending on the capacity of the machine.

**Safety**

Operating the guillotine.

Before operating the guillotine, ensure the following.

- The machine is in a safe operating condition.
- Guards are in place.
- Blade clearance gap and rake angle are set correctly.
- The material to be cut is within the capacity of the machine.
- The material is under at least one holding down ram.
- Only one operator is controlling the machine.
- No personnel are behind the machine.
- Fingers or hands are kept clear at all times.
The universal plate worker

The universal plate worker is an extremely versatile machine, very powerful and sturdy in construction (Fig 5.3).

Work stations

- Plate shearing station
- Vertical cropper station
- Notching station
- Punching station.

These machines are very versatile and are capable of performing five separate and independent operations, namely:

- shearing
- vertical cropping
- oblique cropping
- notching
- punching.
The plate shear can be used for cutting plates and flat bar. Depending on the machine capacity, the length of shear blade may vary from approximately 180 mm to 350 mm in length (Fig 5.4).

Fig 5.4 (a) – Plate shearing station

Fig 5.4 (b) – Rear view with guard raised
### Term and Definition

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>notching</td>
<td>an action that removes small chunks of material and is sometimes referred to as nibbling</td>
</tr>
<tr>
<td>punching</td>
<td>an action that forces a blank out of the material</td>
</tr>
</tbody>
</table>

Because of the length of the shear blade for long cuts, it will be necessary for the cutting operation to be carried out by making a series of small cuts until the cut is complete. For cutting flats in one stroke of the blade, for example with a standard top shear blade of 180 mm long, a flat bar of 80 mm x 12 mm maximum may be cut.

If larger flat bar is required to be cut in one stroke, it will be necessary to exchange the top shear blade for a special shear blade. These special blades are available with various angles, and are designed to change the rake angle of cutting to suit various material types and thickness.

For example:

- a top blade 180 mm long with a blade angle of 1° 30’ is able to cut flat bar from 150 mm x 8 mm to 170 mm x 6 mm in one stroke
- a top blade 180 mm long with a blade angle of 5° is able to cut flat bar 100 mm x 12 mm.

Check the capacity of the machine.

---

Whilst these examples are accurate for a particular make and model of universal plate worker, specifications will vary between different machines.

In addition, the capacities given are usually based on mild steel. Higher tensile steels and alloy steels are sheared and punched on a proportional basis of capacity.
Vertical cropper (bar cutting)

The vertical cropper is generally equipped with standard shear blades for cutting bar sections such as solid squares and rounds (Fig 5.5). In addition, special non-standard blades can be supplied for cutting flats, Z sections, channels, beams and other special non-standard profiles.
Oblique cropper (angle shear)

The oblique cropper is generally equipped with standard shear blades for cutting equal angles, unequal angles and tee sections (Fig 5.7 (a) and (b)). In addition, special non-standard blades can also be supplied to cut channels, beams, flats, and other special non-standard profiles (Fig 5.8).

An important feature of the oblique cropper is its ability to cut angles and tees at 45°.

Fig 5.6 – Special blades for vertical cropper (examples only)

Fig 5.7 (a) – Oblique cutting station

Fig 5.7 (b) – Rear view with guard raised
Fig 5.8 – Special blades for oblique cropper (examples only)
**Notcher (cropper notcher)**

The notcher is generally equipped with a rectangular or triangular shear blade for cutting slots in angles and flats (Fig 5.9). The 90° triangular notcher may be used to cut 90° notches from angles, thus enabling the angle to be readily and accurately bent to 90° (Fig 5.10).

![Photograph courtesy of Fiora Machinery](image)

**(a)**

**Fig 5.9 (a) and (b) – The notcher station**
Another important feature of the notcher is its ability to be fitted with special notching shear blades, for example shear blades are available for cutting a radius on the ends of flat bars and cutting tubes. Interchangeable blades are available to suit various tube diameters (Fig 5.11).

Punch

The punch is generally equipped to punch a range of round holes (Fig 5.12). Of particular importance is the machine’s ability to be fitted with a wide selection of die block combinations to punch various different hole shapes (Fig 5.13). As a general rule, the maximum plate thickness is 0.8 of the hole diameter to be punched.
Fig 5.12 – The punching station

Fig 5.13 – Selection of hole shapes that can be produced by punching (examples only)

Special gooseneck die holder supports are also available to extend the range for punching large beams and channels (Fig 5.14).
Chapter 5 – Mechanical cutting

Gooseneck die support

By the use of the gooseneck, a wide range of sections can be punched.

Fig 5.14 – Gooseneck shape die holder support

Punch fitting

When changing the punch and bottom die, care should be taken to ensure that the punch aligns up with the bottom die and that the bottom die is fitted with the larger hole to the bottom. Failure to correctly align these components will cause damage to the equipment, and may also result in a hardened chip flying from the machine and striking the operator.

Fig 5.15 – Punch fitting
Safety

Operating the universal plate worker

Before starting up and operating the universal plate worker, make sure that the safety protections are fixed and the following rules are complied with.

1. Always operate the machine with all guards in place, at all work stations.
2. Only use one work station at a time.
3. Operate the shear and cropper stations with the hold downs fitted to the feed side of the shears and correctly adjusted.
4. Operate the punching station with the hold down correctly adjusted, and the provided guard fixed in position at the front of the punch. These two points prevent punch breakage and protect your limbs.
5. Watch out for leverage or kick back action when using the notcher station.
6. Never service or maintain the machine or replace any tooling unless the machine has been completely isolated from the main electrical supply.
Sheared edges

Most of the machines discussed in this chapter produce a sheared edge. For general fabrication purposes a sheared edge is usually acceptable, but in some cases, the edge must be ground back to remove the metal affected by the shearing action.

**Fig 5.16 – Effects of blade clearance**

Fig 5.16 indicates the action of a shearing blade. Even with a correctly adjusted blade clearance, the edge will be deformed because of the tearing apart of the metal. Fig 5.17 illustrates the finished cut.
The edge produced by a guillotine is usually of better quality than an edge produced by a universal plate worker, but both edges are suitable for general fabrication.

When considering the speed of the processes (shearing, notching, etc), it should be compared with other cutting processes such as oxygen/fuel gas cutting, friction saws, cold saws, hacksaws etc. From a production point of view, shearing is faster than other cutting processes. If care is taken when using shearing equipment, accuracy is adequate for general fabrication.
Chapter 5 – Mechanical cutting

Power saws and sawing

The saw was one of the first tools developed by primitive man. The teeth of their primitive saws were probably made of chips of flint with rough, sharp jagged edges. Modern day saws are produced in a number of shapes and sizes.

There are three basic cutting motions employed when power sawing:

- reciprocal cutting
- continuous rotary cutting
- continuous straight cutting.

Reciprocal cutting

The cutting action employed when using a hand held hacksaw or wood saw is a reciprocating one. This action may be defined as a slicing motion to cut the work piece. The reciprocating power saw is very common in metal fabrication workshops, however it is rapidly being superseded by the more efficient continuous straight cutting type band saw.

The disadvantage of the reciprocating saw is that the saw blade is never used to its full cutting potential. It is not possible to make use of all of the saw blade teeth.

Cutting time is also totally lost on the return stroke of the blade as it does not cut, the saw blade is also very thick. In comparison with the thinner band saw, this results in a larger amount of non-usable scrap saw chips.

Photograph courtesy of Fiora Machinery

Fig 5.18 – Power hacksaw from the 1930s
Continuous rotary cutting

The circular blade cold saw or the circular blade wood saw are examples of saws that employ a continuous rotary motion cutting action. The saw blade is a non-flexible circular shaped blade with a series of single point cutting edges located around the circumference of the blade. The main advantage of the cold cut saw is its ability to cut large steel sections accurately. Usually this type of machine is stationary and cannot be moved around the workshop.

Friction cut-off saws are smaller, portable saws that use a high speed cut-off wheel and are used mostly on site for cutting thinner steel sections. Care should be taken when using these saws, as too much cutting pressure may cause blade jamming and fracture.

Cuts are adequate for simple fabrications, but tend to veer off when too much pressure is applied or thicker sections are cut. These saws also produce significant noise and dust, and often leave a burr on the underside of the completed cut.
Continuous straight cutting

The horizontal and vertical band saw are examples of saws that employ a continuous straight cutting motion. This is accomplished by using a continuous flexible oval shaped saw blade. At the cutting area, the blade is tensioned and straightened out by roller bearing blade guides. The blade only moves in one direction, therefore the cutting motion is continuous and in a straight line. The horizontal and vertical type saws are the most efficient type of mechanical saws available. Their application is very wide and diverse, as they are able to cut a wide range of material types.

Horizontal band saw machine

The horizontal band saw (Fig 5.21) is used almost exclusively for cutting material to length and width in order to prepare the work piece for further processing. It is eminently suited for cutting solid bar, tubes, sections of steel and other non-ferrous metals.
The main features of this type of machine are its simple operation rapid clamping of stock, in mitre vice with scales, stepless variable hydraulic feed and blade guides for accurate cutting, easy and quick saw blade change facilities, and electrically driven coolant pump.

**Clamping of stock**

The work holding vice on the horizontal band saw is operated manually. The vice jaws can be set to any angle from 90° to 45°, with the aid of a scale to facilitate accurate angle cutting (Fig 5.22).
A stepless hydraulic damping cylinder is provided to give a smooth continuous downward movement of the saw head without placing undue strain upon the saw blade. The hydraulic cylinder permits stepless variation of downfeed, therefore adjustments can be made to feed rates to compensate for the toughness of the material being cut. Downwood feed rates, for aluminium for example, may be faster than those for mild steel. The machine down feed can be stopped in any position and automatically stopped by a motor cut out at the completion of the cut.

Replacement of band saw blades
Changing the saw blade is quick and simple. The machine guards are hinged open and the tension on the saw blade is released with the hand wheel and slide, the blade guides are released by means of clamping levers, and swung aside to release the band saw. When installing the replacement band saw, ensure that the saw teeth are facing the correct way and the blade is correctly tensioned (Fig 5.24).
The coolant pump
The coolant from the work drains through a strainer into the coolant tank. The electrically driven pump draws filtered coolant from the coolant tank and delivers it to the cutting area.

Using cutting fluids
The energy used in sawing appears in the form of heat. Most of this heat is generated at the point of the tool by friction between the tool and the work piece. A stream of coolant is directed to the point of cutting to carry away this heat, which otherwise may break down the cutting edge of the saw teeth.

Cutting fluid flow is an important factor, the flow should not only be copious but the fluid should flow gently onto the work piece. When high pressure is used or when the nozzle is too far from the work, excessive splashing may result. This is wasteful and reduces the cooling action. It is very important to keep the coolant tank topped up, as it must contain enough fluid to dissipate all the heat. Overheated fluid may cause a breakdown in its lubricating qualities.

Coolant type
Soluble oil is recommended for most jobbing work, excepting soft cast brass and cast iron. For expert advice on recommended coolant types, contact the manufacturer’s agent.
Vertical band saw machine

The vertical band saw may be used for cutting off, however, the narrow blade makes possible the accurate sawing of radii from approximately 2 mm, increasing without restriction. The job is guided and fed manually, which enables unusual and irregular curves to be cut accurately. Vertical band saw machines are made in a wide variety of sizes and designs. Fig 5.25 is typical of the type found in metal fabrication workshops.

![Vertical band saw machine diagram]

The running direction of the saw band gives this type of machine its name. The saw runs over two carrier wheels that guide, drive and give tension to the blade during the cutting action. The lower carrier wheel drives the saw band, while the upper wheel is an idler that can be adjusted to control the alignment of the saw band. As the band leaves the upper carrier wheel, it passes through two sets of saw guides, one set above, the other below the table.

The table supports the work, enabling it to be fed to the saw blade. The table has a machined surface, which has T slots running parallel to the direction of the feed; these slots are used to accommodate work holding fixtures, bolts or parallel strips, and to clamp align or guide the work if required.
Band saw speed

The speed of the band saw is measured by the number of linear metres of the saw blade that pass a given point in one minute. Band saw speed is specified in surface metres per minute (m/min). The actual speed at which the band saw travels will depend upon the size of the machine, the size and kind of material being cut, and the size and type of material of the saw blade.

The light type of machine has a speed range from 12 to 2000 (m/min). Heavy duty machines with higher horsepower motors have speeds ranging from 14 to 3600 (m/min). The position of the belt, pulley, and gears must be changed to obtain the full range of speeds.

Fig 5.26 – Parts of a band saw machine exposed to show the upper and lower band-carrier wheels
Saw tooth terminology

Saw blades are constructed from various grades of steels, depending upon their use. High carbon steel blades prove to be satisfactory for soft materials whereas high speed alloy blades are more suited for harder materials. Saw blades consist of specific parts, as follows.

- **Front edge** or tip, is the cutting edge of the blade.
- **The face** of the tooth is the forward edge which forms the chip.
- **The gullet** is the curved area between teeth at the base of the face. Its primary purpose is to remove the generated chip from the work material.
- **Rake angle** refers to the angle made by the tooth measured perpendicular from the cutting edge and the back edge of the tooth.
- **Pitch** is the number of teeth per 25 mm, measured from the top of one tooth to the respective point of another tooth.
- **Gauge** refers to the thickness of the blades backing.
- **Tooth set** is a common element among saws, it refers to the offset of the cutting teeth on each side of the blade. Offset provides the necessary clearance between the saw’s body and the work piece. As the saw passes through the work material, the tooth offset produces an enlarged path called the kerf.
- **Kerf** is the width of the removed materials.
- **Saw blade selection** is important, as the different shapes of saw blade teeth can be obtained in several sizes. The tooth is smaller or larger proportionately so that its cutting efficiency is unimpaired. The thickness of the metal to be cut is the principal factor in selecting the correct pitch. Two teeth should be in contact with the metal being sawn. A fine tooth saw with more teeth per 25 mm should be used on thin metal. Thick or heavy metal will permit the use of a coarser tooth with fewer teeth per 25 mm and a lower number of pitch.

![Saw blade terminology diagram](image-url)
Drills, drilling and drilling machines

Drilling machines
Machines used for drilling can be classified as either stationary or portable.

Stationary machines
The major types of stationary machines are:
- radial arm
- column type
- bench drill press.

Radial arm drilling machine
Fig 5.28 illustrates a medium duty type of radial arm drilling machine. These machines consist of a horizontal arm capable of rotating around and also sliding up and down a fixed vertical column at the end of it. This horizontal arm carries the necessary equipment for the drilling operation to be carried out.

![Fig 5.28 – Radial arm drill](image)
Column type drilling machine

The column type drilling machines illustrated in Fig 5.29 are lighter in construction than a radial arm drilling machine and do not have the same capacity. Horizontal movement of the drill is also restricted, but this depends on the construction of the drill. Machines mounted on the floor are usually called column drills, whereas those mounted on a bench top are called a bench drill press.

The heavy duty type has features that include a:

- heavy rigid frame to reduce vibration
- gearbox drive for increased range of speeds
- direct coupled motor to eliminate slip
- power feed through a quick change feed gearbox
- forward and reverse speed option for tapping
- coolant pump and tank.

Fig 5.29 – Column type drilling machines
Bench drill press
The bench drill press usually has a chuck capacity of 12–15 mm and is similar, but smaller, than those shown in Fig 5.29.

Types of drill bits
- Straight shank twist drill.
- Taper shank (morse) twist drill.

Straight or parallel shank drill
This type of drill is made from high speed steel, and can be run at faster speeds than ordinary carbon steel drills. It can be used with hand or portable drilling machines as well as the fixed machines.

Taper shank (morse) drill
These drills are also made from the higher speed tool steel and can therefore travel at variable speeds (Fig 5.30).

Fig 5.30 – Morse tapers and taper shank drill
Principal features of a drill

Shank

The part of the drill by which it is held in the machine is called the shank. Straight shank drills are held in a drill chuck (Fig 5.31 (a)).

Taper shank drills fit directly into the tapered socket in the drilling machine spindle. The tapers used are known as the 'Morse Standard tapers'.

The functions of the taper are to locate and drive the drill while the function of the tang is to enable the removal of the drill with the aid of a drift (Fig 5.30).

![Diagram of drill parts](a) (b)

**Fig 5.31 – Parts of a drills, (a) and (b)**
Body
The body extends from the shank to the drill point and includes the following.

Point angle
The angle included by the cutting edges, usually 118°, but may be varied to suit different materials (Fig 5.32). The point angle must be equally disposed about the centre line of the drill, otherwise the drill will cut oversize.

![Fig 5.32 – Angle of drill point for general purpose](image)

Flutes
Flutes run the full length of the body and have several functions. They can:
- form cutting edges
- provide necessary rake angle
- access for the cutting lubricant
- swarf removal.

Lip or cutting clearance
The lip or cutting clearance is the relief angle behind the cutting edge that enables the drill to cut. In most cases, an angle of 12–15° is adopted.

Lands
The lands run along the leading edge of the flutes and act as a guide in the hole already drilled.

Body clearance
This is the cut away portion behind the lands, and is incorporated to reduce friction.

Length clearance
A drill tapers back towards the shank to reduce the tendency of binding in deep holes. This taper is approximately 0.02 mm per 25 mm length.
Drill sharpening

How to grind a drill

It is necessary for a drill to be properly ground if a good quality hole is to be produced and unnecessary wear to, or breakage of, the drill is to be avoided.

Points to observe

To obtain satisfactory results with a drill apply the following.

- The point is ground to an included angle of 118° (Fig 5.32). This angle is suitable for most purposes and on standard drills results in the cutting edge of the drill being straight. Angles greater than 118° (125–140°) are used for metals difficult to drill, such as steel forgings and alloy steels.
- Angles less than 118° (90–100°) are used for ease of penetration when drilling brass, soft cast iron, and the light alloys (aluminium etc).
- The angles of the cutting edges to the axis of the drill are made equal (59°).
- The lengths of the cutting edges are made equal.
- The clearance angle of the lip is 12–15° for average purposes (see Fig 5.33).

![Fig 5.33 – Lip clearance for general purposes](image-url)
Machine grinding

The use of this method is recommended wherever possible. Because of the fixed relationship between the drill and the grinding wheel, a point on the drill of the correct angle and equal cutting edges and lip clearances are produced (Fig 5.34).

Hand grinding

If the drill has to be ground by hand, great care and skill are necessary. The drill may be applied to the face of an ordinary grinding wheel or to the side of a recessed grinding wheel, and a gauge used to check the angles and the lengths of the cutting edges as shown in Fig 5.35.

Care should be taken to avoid overheating the drill, and if the drill is made from high speed steel it should not, if very hot, be cooled in water, as fine cracks may develop.

Fig 5.34 – Machine grinding

Fig 5.35 – Testing with a gauge
Speed and feed for drilling

Cutting speed

When we refer to the cutting speed of a drill, we mean the surface or peripheral speed at the circumference of the drill, measured in metres per minute (m/min).

Selection of cutting speeds

This is governed principally by:

- the kind of material to be drilled and its condition, and
- the type of steel from which the drill is made.

Other factors such as size, the type of machine and its condition, the method of cooling the drill, the depth of the hole and the finish required also have to be considered.

To calculate drilling speeds in revolutions per minute (RPM) to suit drills of various diameters, the following formula may be used.

\[
RPM = \frac{300 \times CS}{\text{drill diameter}} \quad (CS = \text{cutting speed} \ - \ \text{metres per minute})
\]

Suggested cutting speeds for high speed steel drills

<table>
<thead>
<tr>
<th>Material</th>
<th>CS metres per minute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mild steel</td>
<td>30</td>
</tr>
<tr>
<td>Grey cast iron</td>
<td>18–30</td>
</tr>
<tr>
<td>Brass</td>
<td>35–60</td>
</tr>
<tr>
<td>Aluminium</td>
<td>60–90</td>
</tr>
<tr>
<td>Alloy steel and stainless steel</td>
<td>15</td>
</tr>
</tbody>
</table>

For practical purposes, when cutting mild steel the above formula may be simplified thus in the following way.

Mild steel only RPM 9000 divided by drill diameter (mm)

Calculated answers can be rounded off to suit available machine drill speed options. It is good practice to try a moderate speed first and then to vary drill speed according to the reactions of the drill and the machine.
Selection of feed

The feed is the rate at which the drill penetrates the work for each revolution.

The selection of a suitable feed is governed by the following.

- The size of the drill – Large drills will withstand coarser feeds.
- The kind of metal – Hard and tough metals are more difficult to penetrate and require finer feeds.
- The type of machine – Large, powerfully driven machines can withstand coarser feeds.

The following table of feeds may be used as a guide.

<table>
<thead>
<tr>
<th>Feed Range</th>
<th>Suitable Drills Diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.02–0.05 mm per revolution</td>
<td>for drills under 3 mm diameter</td>
</tr>
<tr>
<td>0.05–0.1 mm per revolution</td>
<td>for drills 3–6 mm diameter</td>
</tr>
<tr>
<td>0.1–0.2 mm per revolution</td>
<td>for drills 6–12 mm diameter</td>
</tr>
<tr>
<td>0.2–0.4 mm per revolution</td>
<td>for drills 12–25 mm diameter</td>
</tr>
</tbody>
</table>

The feed is operated either by hand or power, depending on the type of machine in use. Most larger machines are provided with power feeds.

To avoid drill breakage, care should be exercised when feeding by hand, particularly when the drill point is breaking through the far side of the work.

Operating small diameter drills at less than their normal speed increases the risk of breakage.

Cutting fluids

The principal functions of a cutting fluid are to:

- lubricate the drill
- cool the drill and the work
- reduce wear
- give a better finish to the hole.

Effort should be made to ensure that the cutting fluid reaches the cutting edges of the drill.

With the exception of cast iron, which is drilled dry, emulsion is the cutting fluid most commonly used on metals such as mild steel, brass and bronze.

Holding the work

The cutting action when drilling tends to cause the work to rotate with the drill. As this could cause injury to the operator and damage to the drill and the work, steps should be taken to prevent movement.

In some cases, the use of one or more stops to prevent rotation is sufficient (Fig 5.36). Very small holes or large heavy pieces of work are often drilled in this manner, the work being held down by hand or by its own mass. In other cases the work must be clamped.
Machine vice

A machine vice is suitable for a large variety of small work and is particularly adaptable to work which is parallel in width and thickness.

The vice should be bolted to the machine table or prevented from rotating by means of a stop.

Clamping to the machine table

When the hole to be drilled has to be at right angles to the base of the work, this method is satisfactory. However, if the hole has to be drilled right through, the work should be supported on parallel strips to avoid drilling the machine table.

Care should be taken to place the parallel strips so that they will support the work efficiently and are clear of the positions of the holes. It is also essential to avoid springing the work with the clamps.
Clamped to an angle plate

This method is ideal when the hole has to be parallel to a piece of the work (Fig 5.39).
Clamped on V blocks

When a hole is required to be drilled at right angles to the axis of cylindrical work, vee blocks should be used to support the work.

Whichever method of supporting the work is adopted, the clamping must be done over points of support and care must be taken to avoid drilling the machine table, parallel strips, V blocks, or machine vice (Fig 5.40).

Fig 5.40 – Work clamped to V blocks
Grinding and grinding machines

Off-hand grinding is the term used to describe grinding when the component to be ground is hand-held. In the metal fabrication trade, grinding may be carried out for:

- removing excess material
- preparing plates for welding
- smoothing surfaces
- sharpening tools such as drills and chisels.

Types of grinding machines

The types of grinders found in the metal fabrication workshop may be:

- pedestal type
- bench type
- portable type (electric or pneumatic).

Pedestal type grinder

The pedestal grinder (Fig 5.41) is usually bolted to the floor. It consists of a heavy frame enclosing the electric motor. The grinder spindle to which the grindstones are attached are driven by vee belts. There is usually an abrasive wheel at each end of the spindle, however in some cases one end of the spindle may be filled with a wire brush.

Photograph courtesy of Fiora Machinery

Fig 5.41 – Pedestal grinder
(note: grindstone not shown in this example)
Adjustable work rests are provided for safely steadying and guiding the work across the face of the grindstone. Work rests should be positioned as close to the grindstone as possible, and should never be allowed to be more than 3 mm away from the grindstone face as the work and fingers could be pulled down between the work rest and the grindstone.

When the grindstone diameter is reduced, due to wear, the work rest can be adjusted back towards the grindstone face.

![Fig 5.42 – Adjustable work rests](image)

**Wheel guards**

All types of grinders have wheel guards (Fig 5.43) and should not be used without them being securely in place. They are an important feature of the machine.

The wheel guard will:

- protect the operator from coming into contact with the rotating wheel
- retain the fragments of the grindstone if it breaks in use
- prevent the fitting of a grindstone that is too large for the machine.
Wheel rotation

The rotation of the grindstone will always be downwards, against the adjustable work rest. The spindle rotation will then tend to tighten the nut holding the grindstone on the spindle (Fig 5.44.)

When replacing a worn grindstone, to determine the rotation direction to remove the holding nut, do the following.

- Stand facing the machine. The spindle on the left should have a left-hand thread. It tightens anti-clockwise
- The spindle on the right should have a right-hand thread. The nut tightens clockwise.
The safe use of grinding wheels
Before commencing the grinding operation, ensure that you are safely dressed. This means:

- no loose sleeves, or flopping ties
- close fitting overalls buttoned to the neck should be worn
- safety glasses must be worn under a clear, full face safety shield
- a leather apron should be worn
- safety boots should be worn.

Leather gloves should NOT be worn during grinding operations.
During grinding operations
Consider the following points when using the pedestal grinder.

- Stand comfortably supported evenly on both feet.
- Position yourself so that the pressure can be applied to the work against the grindstone face.
- Position your body and your hands so that if you or the work slip, your hands will not come in contact with the revolving grindstone.
- Ensure that the work is at the correct angle, well supported by the adjustable work rest. Never hold the work at such an angle or position that it can become jammed between the grindstone and the adjustable work rest.
- Use only the face of the grindstone, the work should be moved across the face whilst grinding to keep the wear on the grindstone even.
- Avoid grinding on the corners of the grindstone, and never use the side of a grindstone unless the machine and grindstone have been designed for this purpose. Side pressure may break the grindstone, or the work may jam between the side of the grindstone and the wheel guard.
- When operating a grinder, it is essential that the operator take steps to eliminate excessive noise levels by wearing correctly fitted ear protection.

Grinding wheels and discs
There are various types of grinding wheels and discs available. They vary in diameter, thickness and composition, depending on the application it is required for.

Grinding wheels and discs are made up of small, sharp stones, bonded together to a required shape, and designed to withstand internal and external pressures. The abrasive stone is compressed of crushed emery made from silicon carbide or aluminium oxide.

The grain size varies and the grindstone should be chosen to suit the finish required (rough or smooth).

Care should be taken when using these grindstones.

- Careless handling could result in grindstones being cracked or chipped. This will cause them to disintegrate when being used.
- Grindstones that become worn and thin should be replaced.
- Grindstones that are clogged or impregnated with metal should be dressed with a steel dresser.
- They should be stored in a dry area because grindstones that become damp could disintegrate when frictional heat is incurred during use.
A wheel dresser is used mostly on pedestal or bench type grinding wheels. Quite often, wheels are worn into grooves by careless operators who do not use the full surface of the grinding wheel. Wheels can also become glazed and lose their cutting power, or become clogged with softer metals like aluminium or copper. They can be restored to a good abrasive surface by using the wheel dresser to remove offending particles.
Chapter 6 – Methods of fastening (bolting)

Connections between structural members may be made in various ways, and can be grouped into two major areas:

1. welded connections
2. mechanical fasteners.

In this chapter we will look at the following.

- Methods of fastening (bolting)
  - bolted joints
    - bolt joint design
    - bolt types
    - bolt installation
    - bolt tensioning
    - washers
    - assembly methods (bolts)
    - bolt joint design considerations
    - masonry anchors.
Bolted joints

Fig 6.1 – Parts of a bolted joint
Minimum edge distance landing

The minimum edge distance that should be used for various steel sections can be found from tables in Australian Standard® (AS) 4100, as per Table 6.1.

<table>
<thead>
<tr>
<th>Nominal diameter of fastener</th>
<th>Sheared or hand flame cut edge</th>
<th>Rolled plate, machine flame cut, sawn or machined edge</th>
<th>Rolled steel section edge</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>mm</td>
<td>mm</td>
<td>mm</td>
</tr>
<tr>
<td>12</td>
<td>21</td>
<td>18</td>
<td>15</td>
</tr>
<tr>
<td>16</td>
<td>28</td>
<td>24</td>
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<td>20</td>
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<td>36</td>
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<td>30</td>
<td>53</td>
<td>45</td>
<td>38</td>
</tr>
<tr>
<td>36</td>
<td>63</td>
<td>54</td>
<td>45</td>
</tr>
</tbody>
</table>

Note: distances vary depending on edge type

Table 6.1 – Minimum edge distances

The basic rule for minimum edge distance is 1.5 times the nominal diameter of the fastener + 3 mm (use rule if distance is not nominated on drawing or AS 4100 reference is not available).

Minimum pitch

The basic rule for minimum pitch or distance between centres shall not be less than 2.5 times the nominal diameter of the fastener.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>pitch</td>
<td>distance between hole centres</td>
</tr>
<tr>
<td>purlin</td>
<td>holds roofing material</td>
</tr>
<tr>
<td>girt</td>
<td>holds side wall material</td>
</tr>
<tr>
<td>cleat</td>
<td>connection from one part or sub assembly to another</td>
</tr>
<tr>
<td>sub-punching</td>
<td>punching a hole smaller than size required</td>
</tr>
<tr>
<td>reaming</td>
<td>removing material to take out hole to size or to align hole</td>
</tr>
</tbody>
</table>
Standard gauge
To make additions or site works easier, designers have attempted to standardise the pitch or gauge between rows of holes.
Whenever possible, gauge lines are nominated at either 70 mm, 90 mm or 140 mm.

<table>
<thead>
<tr>
<th>70 mm</th>
<th>90 mm</th>
<th>140 mm</th>
</tr>
</thead>
</table>

Fig 6.2 – Gauge line

Bolt sizes
There has also been an attempt to introduce standard applications for bolts and bolt sizes. For example, commercial bolts are used as follows:
- M10, 12 purlin and girt applications
- M16 cleats, brackets, bracing
- M20, 24 general structural connections, holding down bolts
- M30, 36 holding down bolts.

Bolt holes
According to AS 4100, the diameter of a bolt hole should be 2 mm larger than the nominal bolt diameter, although larger clearances are permitted. The allowance for holding down bolts is 5 mm larger to allow for movement on site. AS 4100 also recommends the use of drilled holes.

Punching of holes is allowed for in low stress applications, provided the recommendations given in the code are followed. It is preferable to sub-punch and ream when a punched hole is used. The use of drifts or reaming is allowed for alignment purposes. Oxy-acetylene cutting is not an acceptable method of preparing bolt holes.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>reaming</td>
<td>enlarging a hole to accurate size. Reaming must be preceded by a drilled or boring operation. Reaming may be performed on either a lathe or a drilling machine.</td>
</tr>
</tbody>
</table>
**Reuse of bolts**

Plain uncoated bolts that are used in simple joints may be used once or twice, however the reuse of coated bolts is not recommended. High strength bolts that have been full tensioned have usually been stretched in excess of the elastic limit, and therefore will be permanently deformed.

The reuse of this type of bolt is not recommended once it has been fully tensioned and then released or relaxed. These bolts may, however, be re-tensioned, providing they stay in the original hole and have not been fully relaxed.
Bolt joint design

A bolted joint is defined as being ‘bolt bearing’ or ‘friction grip’, depending on joint design and how the bolt carries the load.

A **bolt bearing joint** is one where the load is taken by the bolt in shear, the load can move about the bolt or the joint itself. This type of joint is often used in tubular structures, provided the building movement is controlled by design or bracing. Other common names for this type of joint are ‘simple’ or ‘flexible’. A grade 4.6 or 8.8 bolt is suitable for this type of joint.

![Fig 6.4 – Bolt bearing joint](image-url)
A friction grip joint restricts any movement between the bolted parts, the bolts do not take the load in shear. The design relies on more complex joints and the friction between component parts and/or plates that is created by the tension of the tightened bolt. Research and testing has proven that friction grip type joints are very effective at transferring load between members.

Another name for this type of joint is ‘high strength structural’. It is often used in rigid or semi rigid cage frames with or without bracing, and for joins or splices in many other types of structures. Grade 8.8 bolts are required for this type of joint.

Fig 6.5 – Friction grip joint
Bolt types

The grade or strength of a fastener is normally specified in terms of the tensile strength, and markings on the head are used to identify the rating of a bolt. The first digit indicates one hundredth of the tensile strength in MPa. The second digit indicates one tenth of the ratio between the yield strength and tensile strength (percentage).

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>tensile strength</td>
<td>pertaining to forces on a body that tend to stretch, or elongate, the body</td>
</tr>
</tbody>
</table>

Example

- A grade 4.6 bolt has a nominal tensile strength of $4 \times 100 = 400$ MPa and a nominal yield strength of $0.6 \times 400 = 240$ MPa.
- A grade 8.8 bolt would have a nominal tensile strength of 800 MPa and nominal yield strength of 640 MPa.

The two basic metric bolt and nut types used in steel buildings are:

- the commercial or black bolt (strength grade 4.6)
- the high strength structural steel bolt (strength grade 8.8).

Bolt types are easily identified by markings on the bolt head, washer, and nut as shown in Fig 6.6 and 6.7.
Fig 6.6 – Commercial or black bolt, nut and washer
Chapter 6 – Methods of fastening (bolting)

Commercial bolts

High strength structural steel bolt

Fig 6.7 – High strength structural steel bolt, nut and washer
Bolt installation
The holes in structural bolted connections can be aligned using a pin drift or podger spanner. Where a bolt cannot be inserted because of misalignment, the use of a reamer is allowed, provided the hole does not become too elongated or out of parallel. Bolts must not be driven in to misaligned holes.

Washer use
Commercial bolts are not usually supplied with washers, although it is common practice to place a washer under the nut. The 4.6/S and 8.8/S procedures do not specifically require the use of a washer. Where 8.8/TF procedures are used, a washer is required under the nut.

When the bolt head is to be rotated, or where a larger than normal hole is used, a washer is required under the bolt head and nut. In both cases, a washer must be placed under the part to be rotated during tightening.

Bolt tensioning
The two levels of bolt tightening used in bolted joints are:

- a ‘snug tight’ level (procedure 4.6/S and 8.8/S)
- a ‘full tension’ level (procedure 8.8/TF and 8.8/S)

S = Snug tighten level
A snug tightened joint is one that has the bolts tightened by the full effort of a person using a standard podger spanner.

T = Tension
A full tensioned joint is one where the bolts are tightened to achieve a specified shank tension.

F = Friction type joint
For example: a procedure 4.6/S uses a commercial bolt that is snug tightened.

A procedure 8.8/TF uses a high strength bolt that is fully tensioned in a friction type joint.

Bolt tensioning methods
The various methods used to full tension a joint are:

- part turn method
- direct tension
  - torque control
  - load indicating washer
  - swage lock fasteners.
Chapter 6 – Methods of fastening (bolting)

Part turn method

The part turn of nut method is carried out on bolts that have been snug tightened in the assembled joint. After snug tightening the bolt shank and nut face are match marked. The nut is then given a final rotation between $\frac{1}{2}$ to $\frac{3}{4}$ of a turn beyond snug tight.

![Part turn of nut method](image)

**Fig 6.8 – Part turn of nut method (a) snug tightened (b) final tensioned**

Direct tension/torque control

The direct tension by torque control method is also carried out on bolts that have been snug tightened in the assembled joint. A special tension indicating spanner or torque controlled wrench is used to tension the bolts to a specified torque. This method is similar to that used in automotive engine assembly.

A special shear drive bolt that has a drive end that shears off when correct tension is achieved has also been designed.

![Shear drive bolt](image)

**Fig 6.9 – Shear drive bolt**

The torque control method cannot be used on some joints, because there needs to be enough room to get the tensioning devices onto the end of the bolt or nut.
Direct tension/load indicating washers (Coronet washer)
The direct tension by load indicating washers method utilises special hardened washers that have protrusions around one face that bear against the non-rotating part (bolt or nut) of the bolted joint. Snug tightening of the assembled joint is followed by measuring of the gap between the protrusions before and after final tensioning of the bolt. When the final specified gap is obtained, the bolt will be correctly tensioned.

Fig 6.10 – Load indicating washers
Direct tension/swage lock fasteners

Swage lock fasteners consist of a central pin and a loose fitting collar. They are installed using a special tool that applies direct tension to the pin and then forces the collar down tight onto the serrated pin. When the correct tension is applied, the shank of the fastener is broken off at the reduced neck.

Swage lock fasteners provide a permanent connection that clamps the material securely together. They are very suited to situations where the loss of fastener tension is undesirable. Swage lock fasteners resist vibration, and will not work loose and are ideally suited for use in transport equipment such as truck chassis and railway rolling stock. They are also used in material handling plants in crushers, conveyors, separators and screens.

Because swage lock fasteners are not threaded, they must be removed by using a special tool that breaks the collar. They can also be removed using a disc grinder or thermal cutting equipment. Special care must be taken to avoid marking the parent material which is often alloy steel.

Fig 6.11 – Swage lock fastener
Washers

Flat washers are used to prevent damage to surfaces, and to prevent distortion of bolts. Tapered washers (like flat washers) are used to prevent damage to surfaces, and prevent distortion of bolts. They are available with 3°, 5°, or 8° angles for use on the inside surfaces of tapered flanged channels and beams, as appropriate. Refer Fig 6.12.

Springlock washers (see Fig 6.13) are used under nuts to prevent them becoming loose where vibration occurs. Lock nuts also service this function (Fig 6.15).

![Fig 6.12 – Various washers](image)

The placement and use of washers generally depends on the following rule; the washer is placed under the head or nut of the bolt depending on which part the spanner will be used, ie if the nut is to be turned, the washer is placed under the nut.

![Fig 6.13 – Springlock washer](image)
Assembly methods (bolts)

Stud bolts
Stud bolts are metal rods treads at each end as shown in Fig 6.14.

![Fig 6.14 – Stud bolts](image)

Lock nuts
Lock nuts and locking devices come in many varieties and are used to stop the nut coming loose. Fig 6.15 illustrates some of the lock nuts used, although metal fabrication tradespersons may not be required to use them.

![Fig 6.15 – Lock nuts and locking devices](image)

Common assembly tools include:
- podger spanner
- box spanner
- adjustable spanner
- open ended spanner
- ring spanner
- torque wrench
- drifts.
Podger spanner
The podger spanner is an open ended spanner with a tapered point at one end which is used for lining up (fairing) holes when assembling fabricated components (Fig 6.16).

Box spanner
The box spanner has a single hexagon socket at 90° to the handle, which has a tapered point. This type of spanner is used to tighten nuts or bolts in confined spaces.
Chapter 6 – Methods of fastening (bolting)

Adjustable spanner

Adjustable spanners are available in sizes from approximately 100 mm length upwards. They are a useful general purpose spanner. Nevertheless, they should not be used where heavy torque loadings are encountered (Fig 6.18). Always use a socket, ring spanner or open jawed spanner in preference to an adjustable spanner.

![Adjustable spanner](image)

**Fig 6.18 – Adjustable spanner**

When using adjustable spanners:

- tighten adjusting nuts so that jaws are tight on the nut
- use the spanner so that the thrust is on the fixed jaw
- where possible, pull on the handle rather than pushing on it (Fig 6.19).

![Using adjustable spanner](image)

**Fig 6.19 – Using an adjustable spanner**
Open ended spanner
Open ended spanners are used for general work, particularly in confined areas where the spanner may be turned over to allow it to be used in small movements. The open jaw spanner is not the most suitable spanner for repetitive work or for very high torque loadings (Fig 6.20).

![Fig 6.20 – Open ended spanner](image)

Selection of open ended spanners
To determine the correct size of spanner to use for metric threaded bolts and nuts measure across the flats of the hexagon head of the bolt or nut. The jaw opening is equal to the distance across the flats (Fig 6.21).

![Fig 6.21 – Metric spanner jaw opening](image)

Ring spanner
The ring spanner has the advantage over the open ended spanner of having more than twice the grip positions on the nut, thus ensuring a more positive hold and less chance of slippage.

![Fig 6.22 – Ring spanner](image)
**Chapter 6 – Methods of fastening (bolting)**

**Torque wrench**

The torque wrench (or tension wrench) allows bolts and nuts to be tightened evenly and accurately to design torque specifications. This tool is used specifically by the metal fabrication tradesperson for tightening high strength structural bolts (HSSB). Sockets used with the torque wrench strength will be of the single hexagon type.

![Torque wrench (manual)](image)

**Drifts**

Drifts are used to align parts being assembled so that all holes are lined up (faired) to admit bolts (Fig 6.24). The three types used by the metal fabrication tradesperson are:

- straight shank
- tapered type
- barrel type drift.

**Straight shank**

The straight shank is used to align several plates for drilling.

**Taper**

The taper is used to line up holes for bolting during assembly.

**Barrel**

The barrel is used to align holes in confined spaces. This type of drift is driven completely through the holes to be lined up.

![Types of drifts](image)

**Fig 6.23 – Torque wrench (manual)**

**Fig 6.24 – Types of drifts, (a) straight, (b) taper, and (c) barrel**
Bolted joint design considerations

When structural engineers are considering methods of connecting members, the choice usually reduces to whether the connection shall be bolted or welded.

Although welded connections are generally superior to bolted connections, a number of factors may lead to the use of bolts. Such factors include the following.

1. Speed and simplicity of erection.
2. Bolted connections allow for dismantling and re-erection, and additions and alterations.
3. Less skilled operators may be employed.
4. The inspection procedure is simplified.
5. Members may be coated prior to assembly.
6. No metallurgical problems with induced stress as with welding.
7. Special materials may be connected, overcoming complicated welding methods.
8. Allows for connection of dissimilar materials.

The chief disadvantage of the bolted connection is that a hole must be provided to accommodate the fastener, and therefore extra material must be allowed to compensate. Furthermore, bolted connections require the components to be lapped, which uses more material and causes lines of stress to deviate through the joint, possibly causing stress concentration and associated problems.

Efficiency of bolted joints

The area surrounding the fastener will usually be the weakest part of a bolted joint. The efficiency of the joint is the ratio between the weakest part of the joint and the solid metal, expressed as a percentage or a decimal fraction.
Modes of failure of bolted joints

Bolted joints are liable to failure in a number of ways. The following diagrams (Fig 6.25) show common types of failure.

Fig 6.25 – Modes of failure of bolted joints
Masonry anchors

Masonry anchors are used to fasten steelwork to masonry, and are often used where embedded anchors are not provided. They can be used when and where required to provide a fast, efficient and economical solution to the problem of fixing steelwork to concrete floors or masonry work.

Anchoring refers to the method of forming up a hole in concrete or masonry work using specially designed percussion drills, carbide tipped rotary drills or even self drilling fasteners. The selected fastener is then inserted into the hole and secured by either expansion or chemical bonding.

The main types of masonry anchors used in the construction field are:

- sleeve or expansion type
- chemical type (may be male/female).

Sleeve type masonry anchors

This type of masonry anchor is inserted into a drilled hole and then expanded into the hole by tightening the nut to pull the tapered end into the sleeve. The main advantage of this type of anchor is the ‘through the hole’ fitting principle, where the hole size required is only slightly larger than the thread size. The examples shown are known as male type masonry anchors, because of the protruding bolt and nut design.

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Fig 6.26 – Sleeve type fastener
Expansion type masonry anchors

This type of masonry anchor is also inserted into a drilled hole, but the hole required is larger than the thread size because of the design. Expansion type anchors are commonly used to locate or fix to floors or walls, and they have excellent holding power that can be used to suspend materials. The examples shown below are known as female type, because of their internal thread design.

Fig 6.27 shows a design that has an internal threaded nut to accept a bolt. The anchor is inserted into the drilled hole and then expanded by tightening a bolt to pull the tapered end into the sleeve.

Fig 6.28 shows a heavy duty anchor. These are used in structural and critical applications as well as being recommended for use in tension zone applications. The reason they are used in these applications relates to the ability of heavy duty anchors to further expand when loaded, should the concrete crack or existing cracks widen under service load.
Chemical anchors

The chemical insert anchors are designed for use in high or dynamic load situations, or along edges where an expansion type anchor may crack away the masonry. The hole is drilled and then cleaned out, and a resin is inserted. The resin can be pre-mixed with a catalyst and then injected into the hole, and a serrated stud is inserted before the resin gels and cures.

An alternative method uses a capsule that containing resin and catalyst that is inserted into the hole. The components are mixed together when the stud is inserted to break the capsule.

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Fig 6.29 – Chemical masonry anchors
Chapter 7 –
Form, shape, bend (parts 1, 2 and 3)

Most materials used in metal fabrication, and especially steel, are able to be bent or deformed into various shapes. Provided a few basic rules are observed, this will result in permanent deformation without causing ultimate material failure. The ability of a material to be bent without failure is related to difference between the yield point and ultimate load failure point of the material, and is often described as ductility. The forming, shaping or bending operation can be carried out when the material is either at room temperature or at elevated temperatures.

In this chapter we will look at the following.

- Form, shape, bend (parts 1, 2 and 3)
  - part 1 – plate rolling
    - types of plate bending rolls
    - method of operation
    - safe use of plate rolling machines
  - part 2 – bending
    - folding
  - part 3 – pressing
    - types of machines
    - hydraulic pressure
    - cold pressing
    - materials
    - safety
    - hot pressing

- Activity.
Chapter 7 – Form, shape, bend (parts 1, 2 and 3)

Part 1 – Plate rolling

The plate bending roll is a most important piece of equipment for fabricators involved in work that requires plates to be formed into curved shapes such as for storage tanks, pressure vessels, transitions (cones) or other cylindrical containers. Some plate rolls can have other attachments fitted to them to allow for bending or rolling of sections such as angle or pipe.

The principle of the plate bending rolls

In plate bending rolls, the material is passed between rolls that are arranged so that they apply pressure to the plate causing it to bend as it travels through them. This pressure is applied evenly as the plate passes through the rolls and the amount of curvature is obtained. The rolling action causes the material to bend about the material neutral axis and the inside to material is compressed and the outer material is stretched.

Types of plate bending rolls

The four basic types of plate bending rolls available to the fabricator are:

- three roll pyramid type rolls
- initial pinch rolls
- four roll double pinch rolls
- pinch–pyramid rolls.

Three roll pyramid type plate bending rolls

The oldest type of plate bending rolls is the three roll pyramid machine. It is the simplest, least expensive and easiest to operate type, and as such is ideal for the learner. It has certain disadvantages, however, which has led to a significant decline in its use in modern industry. These disadvantages will be discussed later.

The rolls of the pyramid type are arranged so that if lines were drawn connecting their centres, an equal angle triangle would be formed, see Fig 7.1.

![Fig 7.1 – Pyramid rolls – top roll adjustable vertically – bottom rolls fixed](image-url)
The top roll is capable of being adjusted vertically and, because it is more heavily loaded, it is of larger diameter than the two bottom rolls. It is the general practice to drive the bottom rolls only, and they are sometimes cut with a few shallow longitudinal grooves; these increase the ‘bite’ of the rolls on the plate and also serve as a useful guide to squaring up material on entry.

Usually machines with rolls in excess of 3000 mm or 4000 mm in length have small supporting rolls under the main bottom rolls to prevent deflection under heavy load service conditions.

Cylinder removal
The top roll is usually extended past a ball end or bearing section, to marry with a vertical jacking screw at the end of the rolls. This screw is used to balance the weight of the top roll so as to relieve the pressure from the outer bearing, which can then be unlocked and swung clear. This feature is necessary to permit removal from the rolls of plates that have been rolled to a closed circular form.

It is important that the jacking screw, when not in use, should be released and not left in its jacking position so as to avoid the possibility of damage being caused by trying to raise the top roll while its extension is in contact with the screw.

Pre-setting plate ends
When rolling cylinders with this type of machine, a portion of the plate at the leading end and at the trailing end remains flat. This is because of the lack of bending action for a distance equal to half the bottom roll spacing, as shown in Fig 7.2.

![Fig 7.2 – Flat portion due to lack of bending action](image)

To achieve rolling of plates into cylinders without any flats being left in the plate one of the following methods for pre-setting the end of the plate must be used.

1. Hammering over the rolls (this method can damage the rolls).
2. Pre-setting the ends of the plate in a press prior to rolling using formers or alternatively standard press tools. This is the most successful method for first class work, eg cylinders and pressure vessels etc (see Figs 7.3 (a) and 7.3 (b)).
3. Using curved ‘rocker’ plates in the rolls to set the ends of the plates (see Figs 7.4 (a) and 7.4 (b)).
Initial pinch plate bending rolls

The initial pinch roll has been (and continues to be) the industry standard for the general purpose fabrication shop. Due to its basic design, as shown in Fig 7.5, the initial pinch roll forms a plate with a more accurate roundness than any other type of machine available currently on the market and in the least number of passes.

Due to its basic simplicity, the initial pinch roll offers a great deal of flexibility, as well as ease of operation. Once the initial pinch is set up according to material thickness, only the bending roll needs to be adjusted to change the curvature of the material being formed. By raising the bending roll while gripping the plate between the pinch rolls, an accurate shape can be obtained repeatedly.
Fig 7.5 – Initial pinch roll configuration
Chapter 7 – Form, shape, bend (parts 1, 2 and 3)

Method of operation

The initial pinch roll forming process (as illustrated in Fig 7.5 (a) through to Fig 7.5 (c)) is quite simple. First, the plate is entered between the pinch rolls and gripped at the very edge of the material to set the plate thickness (initial pinch). Next, the bending roll is brought upward slowly before the plate is rolled out for a short distance to form the proper bending radius for the finished product. Once the correct bending force is obtained (by trial bends), the next step is to remove the plate, (noting that the pinch roll and forming rolls remain at their set position) and re-insert the other end of the plate, turning the drive rolls and thus finishing the cylinder. In most cases further plates can be pre-formed and finished in very quick fashion, as little adjustment is necessary to the bending rolls.

Common practice is to leave the plate hooked to the overhead crane or other feeding mechanism while pre-forming the first end, then to simply back it out of the machine and spin it 180 degrees so it can re-enter to finish the cylinder. As can be seen in the illustrations, this is a very rapid and simple procedure. As the plate is gripped during all forming operations, there is no chance of skew or slippage which can cause the plate to come out of the machine. Also, the continuous pinching pressure being exerted assists in uniform forming of the plate while it is being rolled.

Advantages

Due to the basic geometry and ease of operation of the initial pinch roll, it has proven over the years to be extremely versatile for the job shop fabricator. As all three rolls are held in an extremely rigid frame, it has a good deal of versatility for both varying plate thicknesses and diameters.

Another feature of the initial pinch roll is its relatively low cost. It is the most popular type of plate bending machine because of its versatility, accuracy and manageable level of operation at reasonable cost.

Limitations

The only drawback apparent to the standard initial pinch roll is the need to enter the plate twice into the machine to fully form a cylinder to the extreme plate ends. It must be noted however, that in larger diameters of lighter wall vessels, turning the plate is not usually necessary as the length from the centre line of the top roll to the centre line of the rear roll of the machine is a rather short distance and the flat area is not very apparent in larger diameters. Many fabricators operate the initial pinch roll in one pass and achieve sufficient quality for general purpose tank fabrication.

The one area where two-plate entry may be a concern to the fabricator is in the rolling of long sheet lengths where building limitations may create a problem in turning. In these instances, either design or material handling systems should be considered.
**Four roll double pinch machine**

The four roll double pinch machine is usually the most expensive machine available on the market, but is an excellent machine for some particular purposes. This machine is especially suitable to fabricators who perform production runs of the same size rolled product on a regular basis. It is also a suitable choice for fabricators who work with long plates that would be difficult to turn around as required for an initial pinch type plate bending roll.

As can be seen in Fig 7.6, the basic roll machine is a very similar concept to that of the initial pinch roll. The two main rolls are configured as a top and bottom pinch roll, and then two additional side rolls are fitted.

The four roll double pinch roll is different from the initial pinch roll in several respects. Besides the presence of the additional roll, it is a symmetrical machine; there is no offset between the two pinch rolls, and this makes it somewhat more difficult to do supplementary edge-forming operations. Secondly the side rolls are usually reduced in size by 20%, as shown in Fig 7.6. This reduction in size of the side rolls makes the four roll a little more limited in its capacity and is related to the higher cost of material in building a four roll.

The basic principle of operation of a four roll is to run it as an initial pinch from both directions. Therefore, the machine is usually run as a three roll machine with the fourth roll acting only during the pre-forming operation. All four rolls contact the plate occasionally when the machine is used for re-rolling.

The four roll machine is the best choice for conical forming, as its geometry allows tilting of the side rolls in the opposite plane from the pinch roll. Also, as it is a symmetrical machine, it is designed for one-entry forming. As the four roll can be engineered for a particular job and process to be performed, it is an excellent machine for high production rolling.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>symmetrical</td>
<td>two halves of an object being equally balanced – as a mirror image</td>
</tr>
</tbody>
</table>
Fig 7.6 – Four roll operation (a) pre-forming one plate end, (b) completing cylinder, and (c) re-rolling operation possible
The combination pyramid-pinch

The combination rolling machine (also referred to as the pyramid-pinch or as the pinch-pyramid machine) is very complex and expensive to make. And as its name would imply, it is a combination of the pyramid design and the pinch design. The original pyramid roll was designed as a true triangular pyramid roll pyramid configuration (see Fig 7.1), with the top roll moveable up and down and the fixed lower two rolls powered.

Although the pyramid roll had many good features, the fact that the lower rolls were fixed in position and could not be brought up to touch the top roll created an end flat when rolling that was equal to the distance from the centre line of the top roll to the centre line of the lower roll. When using a normal pyramid type rolling machine and to prevent flats caused by the design, the fabricator is forced to preset the cylinder ends, or roll the cylinder, cut the ends off, and finish roll again.

The combination pinch-pyramid machine utilises the pyramid roll configuration, but has the top roll fixed in position and the lower rolls are adjustable upward, either in an angular fashion or a pivoting fashion, as shown in. The concept of the combination machine is to allow the fabricator to bring one lower roll up to act as a pinch roll while using the other lower roll as the rear forming roll, as shown in Fig 7.7. In this fashion, a plate can be fully formed with one entry into the machine. However, a good deal of operator skill is required to balance the positioning of these two lower rolls.

One of the problems that can become apparent, if the sheet is long when pinching, is that one end will drag the floor. Also, when lowering the pinch roll and running the plate through to bring the other side roll up to become the pinch roll, it is possible to lose grip on the plate and have the plate slide sideways or go out of square, which would cause a skew. However, when operated properly, the combination machine can form a good cylinder.

It must be noted that this machine is primarily recommended for large diameter tank work. When the bending action is taking place below the top roll, more air-bending is being done and normally the machine is not capable of forming the smaller ‘pipe’ diameters possible on the initial pinch roll.

![Fig 7.7 – Combination pinch-pyramid configuration](image-url)
### Summary of advantages and limitations

<table>
<thead>
<tr>
<th>Type</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pyramid type</td>
<td>• least expensive</td>
<td>• extensive pre-setting (pre-forming) required</td>
</tr>
<tr>
<td></td>
<td>• simplest to operate</td>
<td>• slow operation</td>
</tr>
<tr>
<td>Initial pinch</td>
<td>• relatively low cost</td>
<td>• pre-setting carried out by machine</td>
</tr>
<tr>
<td></td>
<td>• fairly easy to operate</td>
<td>• pre-setting carried out by machine</td>
</tr>
<tr>
<td></td>
<td>• very versatile in terms of plate thicknesses and diameters</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• little chance of skew slippage</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• very accurate in terms of absence of flats</td>
<td></td>
</tr>
<tr>
<td>Four roll double pinch</td>
<td>• plate needs to be entered only once</td>
<td>• very expensive</td>
</tr>
<tr>
<td></td>
<td>• ideal for production work</td>
<td>• not versatile, limited in capacity</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• requires expert operation</td>
</tr>
<tr>
<td>Combination pinch-pyramid</td>
<td>• ideal for large cylindrical tank plates</td>
<td>• pre-setting carried out by machine</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• fairly expensive</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• not recommended for small diameters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• requires expert operation</td>
</tr>
</tbody>
</table>
Calculations (cylinders and curved work)

During the rolling operation, the outside circumference of the plate is stretched and the inside circumference is compacted. Calculation for cylindrical or curved work must take into account an allowance for metal thickness.

Neutral axis

In the exact centre of the metal thickness is an imaginary line known as the neutral axis. This line does not change its length during the bending operation, and it is on this line that calculations for curved work must be made.

Fig 7.8 – Neutral axis example
Mean diameter

Workshop drawings almost always specify the inside diameter (I/D) or outside diameter (O/D) for curved work. These diameters must be adjusted to the neutral axis or, as it is more commonly referred to, the mean diameter (M/D).

M/D is calculated by subtracting the allowance for metal thickness from the O/D, or adding the allowance for metal thickness to the I/D.

\[ \text{Eg } M/D = O/D - \text{plate thickness or I/D + plate thickness.} \]

Example 1

Find the size of material required to roll up a cylinder of the following dimensions:

- length 2800, O/D 450, material thickness 12.

![Diagram showing the calculation of mean diameter](image)

\[
\begin{align*}
\text{Mean dia} &= O/D - t \\
&= 450 - 12 \\
&= 438 \\
\text{Mean circ} &= \text{Mean dia} \times \pi \\
&= 438 \times 3.1416 \\
&= 1376.02 \text{ mm}
\end{align*}
\]

\[ \text{Reqd. size of plate} = 2800 \times 1376 \times 12 \]

Fig 7.9 – Mean diameter example 1
Example 2
It is required to roll up a ring from Ø 33 bar to fit neatly around a cylinder of 3100 O/D. Find the length of bar required.

\[
\text{O/D Cylinder} = \text{I/D of bar} \\
\text{Mean dia} = \text{I/D of bar} + \text{bar dia} = 3100 + 33 = 3133 \\
\text{Mean circ} = \text{Mean dia} \times \pi = 3133 \times 3.1416 = 9843
\]

\[\text{Reqd. length of bar = 9843 mm}\]

Weld preparation
It is usually best to make the weld preparations on the flat plate before rolling. If a gap is required at the longitudinal joint, the gap allowance should be included in the calculations for the length of plate required. When entering the plate into the rolls, care should be taken to ensure that the weld preparation is correctly positioned (usually with the vee on the outer side).

Marking out
If any reference marks or pattern lines etc are marked on the plate prior to rolling, ensure the plate is entered so that these marks or lines will be on the outside of the rolled cylinder.

Templates or sweeps
Templates or sweeps are generally used to check the set or pre-bend of the plate ends prior to rolling, and also to check the sweep of the cylinder as the plate is being shaped in the rolls.

Templates may be of the outside type, depending on the method used to set the ends or the diameter and length of the cylinder that is to be rolled. Inside templates are cut to the inside radius of the cylinder (see Fig 7.11 (a)).

The outside template is shaped to the outside dimensions of the cylinder (see Fig 7.11 (b)).
Templates may be made from thin galvanised iron sheet cut into shape with tin snips; this is the usual case when only a few cylinders have to be rolled to the one size. However, when there are a number of plates to be set and rolled to shape, a heavier template cut from 3 mm plate is sometimes required. These can be shaped by mechanical cutting methods and should be checked for accuracy after manufacture.

**Preparation for rolling – pyramid**

Before rolling can be commenced, the following points should be observed.

- Pre-set or crimp plate ends to the desired curvature, taking care to provide enough set so as to avoid flats occurring when the job is completed.
- See that the plate is free from raised encrustation, weld beads etc.
- Position the plate squarely in the rolls. This may be done by using a large plate square, or by mating the edge or centre lines of the plate with the grooves on the bottom rolls.
- Apply initial weight to secure the plate in the squared position and commence rolling.

The last two points should be carefully observed so that the cylinder being formed is rolled square with the edges meeting, to avoid unnecessary work.
Safe use of plate rolling machines

- Ensure that the top roll jacking screw is in the raised position before making any adjustment to the machine.
- Never lean on a machine, even when it is stationary.
- Only one operator to use the machine at the one time.
- Do not wear gloves when rolling plate.
- Keep hands and clothes clear of plate when rolling.
- Increase roller pressure on adjusting screws slowly for each pass of the plate through the rolls.
- Beware of the double thickness of plate that occurs during over-rolling and make sure this does not pass between the top and bottom rolls.
- Ensure that the plate is not allowed to pass back too far through the rolls when approaching the ends. It may fall out of the machine or at least become out of square.
- When removing rocker plate from rolls, first fully raise top roller and then lift plate out by hand. DO NOT attempt to drive it out by rotating the rollers.

Technique of plate rolling

When the cylinder is rolled so that the edges meet, it may be tack welded or bolted prior to removal, and then placed in a cradle for further ‘rounding up’ if necessary. Cylinders should be over-rolled to allow for the tendency of the plate to spring, due to the elasticity of the metal. The amount of over-rolling can only be determined by experience. Particular care must be taken with small diameter cylinders, where it is impossible to get inside to do any hammering. Large diameter cylinders made of thin plate (say 5 mm) should be supported by an overhead crane until the plate has sufficient curvature to support itself.

Some rolls have a replaceable top roller for widening their range of work. In general, the minimum diameter of a cylinder capable of being rolled with set ends is about 1.5 times the top roll diameter. The capacity of plate bending rolls is usually expressed in terms of maximum thickness that can be rolled, maximum plate width and the diameter of the smallest cylinder that can be rolled. This is 8 mm maximum thickness x 2000 x 190 min diameter.

When thin plates or bars with very little width have to be curved, sometimes the resistance of the materials is insufficient to cause friction between the free roll and drive rolls, and the material tends to remain stationary.

All plate bending rolls are fitted with some form of loose end drop end for removal of completed cylinders, on larger machines. This may be hydraulic.

Speed of rolling

With the pyramid type rolls, the plate should be rolled in easy stages, applying the weight progressively while the rolls are in motion. This is not possible with some types of rolls that are manually operated.

The pinch type or self setting type plate benders can complete rolling operations in relatively few passes compared with the pyramid types.
Re-rolling

If the cylinder is rolled, handled and welded properly, re-rolling should not be necessary. However, if the cylinder is improperly formed and already welded, some re-rolling may be necessary. In most cases, re-rolling requires more pressure then initial rolling. Re-rolling is hard on a machine because there is no open end that can move and the diameter changes.

**Note**

Great care must be taken when attempting to remove flat or peaked areas. Excessive pressure applied during re-rolling can result in an oval shape being formed.

Rolling conical sections

Plate bending machines can be used to form conical frustums, providing the taper is not too great. Generally the limitation is a ratio of 1:2 with reference to the radius at the top of the frustum to the radius at the base of the one cone, see Fig 7.12.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>conical frustum</td>
<td>basically a right cone with its top sliced off parallel to its base</td>
</tr>
</tbody>
</table>

**Fig 7.12**– Ratio of top to base of conical frustum pattern
(conical sections with a steeper ratio, greater than 1:2 are usually formed in a press brake)
Snubber (hold back) attachment
A plate being pulled into the rolling machine will be pulled at the same speed throughout its length unless some means is used to retard one end. Simply tilting the rolls will form a spiral rather than a true conical form.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>snubber</td>
<td>an attachment fitted to rolling machines that is used to skew material when rolling conical shapes</td>
</tr>
<tr>
<td>green</td>
<td>addition material on a work piece that is be removed once work has been completed</td>
</tr>
</tbody>
</table>

A snubber or hold back attachment is a simple means of achieving a conical shape with relative ease. The function of the snubber is to retard the smaller radius and line up the bend to the radial lines as it passes through the machine. If the snubber is correctly placed and the pattern for the conical frustum properly developed, most conical shapes can be formed without tilting the rolls. The snubber should retard the small radius end so that a radial line of the plate from the cone apex will be parallel with the rolls at the point of the bend.

Fixed snubber assemblies
Some machines have a snubber device incorporated in the machine. In the case of pyramid type rolls, the snubber, if provided in the machine, is located between the bottom rolls and can be adjusted vertically by means of a spring loaded handle, see Fig 7.13. The snubber attachment is wound back clear when not in use and wound up to just below the top roller when rolling cones. This design is difficult to use as the snubber roll must be adjusted whenever the top roll is adjusted.

![Fig 7.13 – End view pyramid rolls with snubber incorporated](image-url)
The snubber is usually made from hardened steel, since a considerable amount of abrasion is exerted upon it. This causes considerable amount of upset on the softer steel at the small radius edge. It is advisable therefore to have a trimming allowance (or green) added at the small radius end.

**Improvised snubbers**

Roll bending machines that don’t have a snubber incorporated can be used to roll conical sections by employing an improvised snubber.

A short section of angle trimmed as shown in Fig 7.14 makes a serviceable snubber. The length of the angle should be sufficient to provide clearance for the plate as it passes through the rolls.

![Fig 7.14 – ASA prepared as shown makes a useful snubber](image)

With the pyramid type rolls, the angle snubber is placed on the leading bottom roll (the side at which the plate enters the rolls) and up against the end post of the machine, see Fig 7.15.

When the plate passes through the rolls, the angle snubber is then moved to the other bottom roll to accommodate the reverse pass.

![Fig 7.15 – Location of angle snubber](image)
**Section rolls (ring rolling machines)**

These machines are specially designed to roll rings of any section, including tube. All section bending rolls operate in the same fashion as pyramid plate bending rolls, i.e., one roller moves toward the space between the other two rollers to increase curvature. End setting is difficult on these machines, so it is usual to allow extra length, roll to the desired curve as close as possible to the ends, then cut off the straight ends.

Section rolls are interchangeable and made in sets to suit the required section. Some machines have rollers on top suitable for very large diameters (Fig 7.16 (a)), while others have rollers mounted on the side (Fig 7.16 (b)).

![Diagram of section rolls (ring rolling machines)](image)

**Fig 7.16 – Two methods of rolling steel sections,**  
(a) top rollers for very large diameters,  
and (b) side rollers
Some rolls have slots so that angles can be rolled either with the leg in or the leg out, see Fig 7.17.

![Fig 7.17 – Roll bending angles in section rolls (a) leg in, and (b) leg out](image)

Certain types of plate bending rolls have extensions through the end bearings to carry ring bending rollers, as per Fig 7.18.

![Photograph courtesy of Ron Mack Machinery](image)

**Fig 7.18 – Plate rolling**
Calculations involved when rolling section rings

The basic calculation is similar to that required for cylinders. However, it will be obvious that the neutral axis will not be in the centre of the section dimensions. In the case of sections, this axis is called the **centre of gravity** (C of G) and is found by reference to manufacturers’ section tables. It is always stated as a dimension from the heel or from the centre line of the section.

Having found the C of G, the mean diameter is calculated, then the required circumference.
Part 2 – Bending/folding

The ability to be able to bend most materials used in metal fabrication and especially steel without failure has been discussed previously. Small steel sections can easily be roughly bent when cold by using applied force.

Sheet material can be roughly bent when cold or hot by using a hammer after being fastened between the jaws of a vice or clamped between two boards.

Machine bending is faster, less damaging and more accurate for sheet metal.

The most common sheet metal bending machines are the bench folder, the cornice brake, and the box and pan brake.
The cornice brake is used for making bends up to 1200 mm long in 1 mm metal.
The pan folder is heavy welded steel construction. The clamping beam is opened and closed by eccentrics and is adjustable to suit metal thickness. The clamping beam can sometimes be lifted at one side to remove closed channels. The bending beam can be adjusted in order to choose the required radius. Maximum bending angle is 135°.

The box and pan folder is of welded steel construction. Boxes of various sizes can be formed up with sides ranging from 20 mm to the full width of the folder by using the range of fingers available. Throat size is restricted by machine type and construction. Eccentric clamping on the upper beam can be adjusted in one operation to suit material thickness.
Photograph courtesy of Fiora Machinery

Fig 7.23 – Box and pan folder
Part 3 – Pressing

Pressing refers to the process of bending material using special machines known as presses. These operations have long been popular with metal fabricators because they produce a neat job, which is both fast and economical. Bending is cheaper than the alternative of fabrication and welding, particularly when many similar shapes or bends are required and initial equipment cost is not a factor.

Hot/cold pressing

Material may be pressed either hot or cold, but hot material offers less resistance and reduces the force required for bending. The load on the press and its tooling is also reduced when hot pressing, because the material is more ductile. Hot pressing is often used on larger jobs or where sharper beds are required. Hot pressing tends to be a specialist process which involves heating and material handling problems and is used mainly by large fabricators when forming heavy materials and intricate shapes.

Cold pressing is more common in structural workshops and metal fabrication tradespersons should be familiar with both the machines required and the processes involved.

Presses

Presses take their name from the fact that metal is pressed between a top and bottom tool, or formers, into the shape required. The tools are held and supported by beams or posts mounted on a heavy frame, and force or pressure is usually exerted either mechanically or hydraulically. The top tool moves vertically on to a fixed lower tool, but some presses have an opposite arrangement.

Presses have a wide range of applications but tend to be adapted to specific operations. In structural workshops they are commonly used in the production of cold bends or the flanging of steel plates. A press is capable of delivering maximum force at any point and may be stopped at any time within its cycle or working stroke.

Press brakes differ from a press, because the length of stroke can be pre-determined, ie adjustable in its downward travel, and will deliver pressure up to its maximum at that point. In flywheel driven press brakes, this feature is very dangerous because once a cycle is begun it will not stop until it has been completed.

The following illustrations of press brakes show a manual fly press and a mechanical flywheel operated machine in Fig 7.24. More modern electro-hydraulic machines are shown in Fig 7.25 and Fig 7.26. Note the various arrangements of the hydraulic rams and the heavy end frames, providing clearance through the ends for longer sections.
Fig 7.24 – Flywheel operated press brake machines (old style)

Photograph courtesy of Ron Mack Machinery

Fig 7.25 – Electro-hydraulic press machines
Fig 7.26 – Deep drawing press
Press brake tools

Standard equipment on a modern press brake is the four way die block and top tool as illustrated in Fig 7.27.

![Fig 7.27 – Four way die block and top tool](image)

Standard tooling is based on the air bend principle and enables bends of 90° or less to be made over a wide range of plate thickness. The square bottom die block allows various sizes of vee to be cut into its four faces, all of which may be used with the same top tool.

The top tool can be obtained in the full length of the top beam or as a sectionnalised blade, i.e. various shorter sections make up the full length. The reason for the shorter lengths is to allow tray formations to be pressed. Different thicknesses of radii may also be obtained for the edge of the top blade, to accommodate the pressing of various plate thicknesses without buckling.

Other variations of top and bottom tool combinations are available to suit special purposes, especially in the sheet metal area as shown in Fig 7.28 (a) and (b).
Fig 7.28 – Various top and bottom tool configurations
Air bending

In air bending (Fig 7.29), spring back is catered for by over-bending, and the material returns to the correct bend. To allow for this, female die blocks are machined with an angle of 85°, as shown.

![Fig 7.29 – Air bending](image)

Air bending enables various angles to be bent by a three point loading. The three points are the two edges of the vee in the bottom die and the edge of the top tool. Advantages of air bending are that:

- less power is required to bend the material
- thicker and wider plates may be bent
- various angles may be formed with the same tooling.

Coining

In coining operations (Fig 7.30) spring back does not occur because of the high loads applied to the press, and the design of the top and bottom tool. The resulting compression removes all elasticity from the plate. Coining tools are machined to the angle required in the finished plate, and bends of high angular accuracy are produced.

![Fig 7.30 – Coining](image)
Die ratio, bend radii and force

Air bending allows thicker materials to be bent with minimum force. The factors that determine how much force is necessary are the:

- width of vee in die block
- radius of bend
- thickness of plate
- width of plate
- strength of material.

The first two factors are important to the operator. Choice of vee for mild steel is usually decided by applying the **standard die ratio**. Standard die ratio is 8:1, ie width of vee should be eight times the plate thickness, as shown in Fig 7.31.

![Figure 7.31 – Standard die ratio](image)

Standard air bend

\[ W = 8t \cdot R = t \]

**Fig 7.31 – Standard die ratio**

Standard die ratio produces bends with an inside radius that is approximately equal to plate thickness. It should be realised that increasing the die ratio will permit bends to be made with less force, but the inside radius will increase. Die ratio may be increased in cases where:

- machine capacity is insufficient for a particular job
- applied loads may damage tooling
- thicker mild steel plates, or tougher and less ductile materials are to be bent
- there is a high risk of cracking.

**Material considerations**

Mild steel is not affected by cracking problems, provided the standard die ratio is used, although cracks may occur at sheared edges if the under side is stretched. Also, during the rolling process the material develops a ‘grain’ running with its longitudinal axis.

Whenever possible, sheared plates should be bent with the rounded upper edge to the outside of bends and bends placed across, rather than along the grain.

Higher tensile steels are tougher than mild steel and less ductile, therefore it follows that more force is required to bend them and the risk of cracking is increased. Die ratios of 10:1 or 12:1 are recommended for high tensile steels.
Most structural metals can be bent satisfactorily, but their strength and ductility varies. The force required to bend some common materials, as compared to mild steel, is given in Table 7.1.

<table>
<thead>
<tr>
<th>Material</th>
<th>Multiplier of Die Opening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless steel</td>
<td>Multiply die ratio by 1.5</td>
</tr>
<tr>
<td>Aluminium – soft temper</td>
<td>Multiply die ratio by 0.25</td>
</tr>
<tr>
<td>Aluminium – hard temper</td>
<td>Multiply die ratio by 0.4</td>
</tr>
<tr>
<td>Aluminium – heat treated</td>
<td>Multiply die ratio by 1.2</td>
</tr>
</tbody>
</table>

Table 7.1 – Press brake operation

Capacity of press

Rated tonnage is clearly shown on press brakes, and a tonnage chart is usually fixed to each machine, as shown in Table 7.2. Press sizes range from 30 to 500 tonnes. Every job does not require a check for machine capacity, but when the upper limit is approached it is advisable. From the chart take the tonnage per metre, which is underlined (across from plate thickness, and down from recommended die opening). Total tonnage is the tonnage per metre multiplied by width of plate, and should not exceed rated tonnage for the press. In modern hydraulic presses, overload will not damage the press, it will just stop, and top tool can be returned by use of the inch return button. Care must be exercised to avoid damage to the top and bottom tools.

Table 7.2 – Tonnage chart
Selection of bottom die

Size of die opening as determined by the standard die ratio has already been dealt with; for example, a 5 mm thick plate x 8 = 40 mm die opening.

It is worthy of mention that this information can be obtained directly from the tonnage charts, by reading vertically above the underlined tonnage for 5 mm thick material.

Careful study of the tonnage chart shows that the standard die ratio has been used up to 12 mm plate thickness. Above this thickness the die ratio may be increased to reduce the bending force required, and reduce the risk of cracking.

For example, a 25 mm thick MS plate by 1 metre wide to be bent in a 150 tonne press.

Method 1: Using standard die ratio

Female die opening = 8 t
= 8 x 25
= 200 mm
Tonnage per metre = 214 tonnes (exceeds press capacity)
Female die opening = 200 mm
Inside radius of bend – 25 mm (equal to thickness)
Minimum leg length = 144 mm

Method 2: Using recommended values from tonnage chart

Tonnage per metre = 143 tonnes (press capacity adequate)
Female die opening = 300 mm
Inside radius of bend = 37.5 mm (increased)
Minimum leg length = 216 mm (increased)

NOTE: Die ratio in method 2 = \( \frac{\text{Female die opening}}{\text{Plate thickness}} \)
= \( \frac{300}{25} \)
= 12:1

From this it may be concluded that when MS plate thicknesses exceed 12 mm, and sharp bends or narrow flanges are not essential, it is advisable to increase the die ratio.

Pressing with a die opening that is too small may create problems such as:

- overloading of machine, inability to do job
- overloading and damage to machine tools
- cracking of the bent material
- gouging of the bent material.
Selection of top tool

Selection of the top tool is also important, as these relatively slender blades are easily damaged. As the thickness of bent material increases, the radius of the top blade edge should also increase. Tool radii approaching the inside radius of bend shown on the tonnage charts are safe to use. Particular care should be taken when plates are thick or when narrow bottom dies are being used.

Changing press tools

Most press brakes are provided with the means of lifting bottom die blocks with the top beam, in such a way that rotation is easy. The raising and lowering of the top beam is done with the inch control, which allows time for the lifting links to be positioned or removed. When lowered with the required vee uppermost, the vee must be carefully centred to the top tool and clamped firmly into position on the bottom beam.

Top tools are fitted into a machined groove and held in position by bolts through a clamping bar. The inch control is used to lower the top blade until it almost rests on timber placed across the bottom die. At this point the bolts are slackened to release the blade, which is slid out at one end. When the new blade is in position, the top beam can be lowered until it resets on the blade before clamp bolts are re-tightened.

Handling plates

Press brakes are normally open fronted, because the movement of plates during bending and the varying size of plates makes it difficult to provide permanent guards and support tables. Handling is improved by the provision of lifting facilities and movable trestles. The tradesman should examine each job and arrange for adequate and safe handling. A useful feature provided with many presses are the cantilever supports which bolt to the lower beam, see Fig 7.33. These can be used to:

- provide back stops which save marking time
- act as supports for material
- ensure that plates are square to the blade.
Theory of bending

Bending rules

There are many variables in plate bending that can effect our marking out allowance and finish dimensions. These include plate thickness, die opening, radius of bend and temperature of the metal when bending. A practical method often used to check on the effects of bending is to carry out a trial bend. Tradespeople, however, only need to consider two basic rules when making allowances in marking out for bending.

Rule 1 – When ‘r’ (radius of the bend) is equal to ‘t’ (thickness), then work to the inside of the bend.

Rule 2 – When ‘r’ (radius of the bend) is more than ‘t’ (thickness), then work to neutral axis of bend.
Neutral axis or mean line

The presence of a neutral axis in bent material needs explanation. Bending causes metal to stretch on the outside and compress on the inside, but at the centre of plate thickness, it is neither stretched nor compressed, see Fig 7.36. As a general rule, the neutral axis will be close to the inner edge of thin plates, but will move towards the centre as plate thickness, or bend radius, increases.
Examples of bending allowance where ‘r’ = 't’

1. When making a job to outside measurements, material thickness must be allowed for.

\[
\begin{array}{ccc}
A & B & C \\
45 & 50 & 45 \\
\end{array}
\]

Fig 7.37 – (A) = 50 – 5 = 45, (B) = 60 – 10 = 50, (C) = 50 – 5 = 45

2. When making a job to inside measurements material thickness is not to be allowed for.

\[
\begin{array}{ccc}
A & B & C \\
50 & 60 & 50 \\
\end{array}
\]

Fig 7.38 – (A) = 50, (B) = 60, (C) = 50
Example bending allowance where ‘r’ is more than ‘t’.

Fig 7.39 – Length before bending = (A) + (B) + (C) = 50 + 47 + 70

Calculations (for neutral axis allowance) (B)

Use a formula similar to that used for circumference of a circle. \((\pi \times \text{diameter})\). The result is then divided by the degree portion \((90^\circ)\) of the bend as a percentage of a full circle \((360^\circ)\). Remember, neutral axis calculations use mean diameter (MD).

Neutral axis mean diameter = 60

\[(B) \text{ from } \pi \times 60 = 188.5 \times .25 (360 \div 90) = 47 \text{ mm.}\]
Spring back
When steel is bent the inner and outer surfaces are highly stressed. The inner is compressed and the surface material is stressed beyond the elastic limit and becomes plastic, retaining its bent shape. There is always some material that is stressed within the elastic limit, it is this steel that tries to regain its original shape when the press load is released and causes ‘spring back’. The material returns very slightly towards its original shape when the bending force is removed.

To compensate for spring back, the bend must always be made a little greater than is required.

Whip-up
When pressing, the ends of plates can be lifted quite rapidly by the press. This is known as whip-up. Operators should be ready for this plate movement and by careful control should minimise the speed at which it occurs. Watch out for your fingers.
Safety – Working with the press brake
Accidents involving crushed hands and lost fingers have often occurred to press operators in the past. To avoid repetition of this, the following points should be considered and followed.

- As an operator, make sure that your hands and your assistant’s hands are safely positioned before operating press.
- Always consider the effects of press operations and keep hands positioned where they are safe, even if the press is accidentally operated.
- During press operations, ensure that no one is behind the machine.
- When operating with an assistant, always discuss procedures carefully so that each person knows exactly what to do and what will happen.
- Remember when pressing that the ends of plates can be lifted quite rapidly by the press, this is known as whip-up. Operators should be ready for this plate movement.
- Whip-up is always followed by release of the plate and rapid return to its original position. As falling plates are another source of trapped hands and strained muscles, operators should always be prepared to control the plate when it is released and to lower it carefully.
- Tidiness is essential for safe press work. Tools and equipment should be constantly cleared from press surfaces, and work areas, to be stored neatly away.

Setting up the press brake
Modern electro-hydraulic press brakes enable the depth of stroke to be set with relative ease. The top tool can be finely adjusted to stop at any point of its stroke, even with the plate in position and under load. This allows an operator to observe the bend being formed, and to set the depth of stroke very precisely. When set, the press will automatically cycle to the same position.

By contrast, earlier presses could not be set with the plate under load. A series of bends were made, gradually adjusting the stroke each time, until the desired bend was obtained. Quick accurate setting required experienced operators.

The following points deal with the setting of a modern press brake.

- Lower blade slowly on automatic to check setting, adjusting if necessary to allow sufficient clearance for plate thickness required.
- Change from automatic to inch control.
- Bring the blade down slowly onto plate, until it stops at the bottom of its stroke.

On inch control the blade will remain at the bottom of its stoke until deliberately released, either by the inch return button, or change back to automatic.
Chapter 7 – Form, shape, bend (parts 1, 2 and 3)

- When blade stops at its lowest position, keep foot control depressed and turn adjusting control until blade comes down far enough to provide sufficient bend.
- Change control switch to automatic, which returns blade to top of stroke.

The adjusting control provides fine adjustment either up or down.

Some features of the modern press brake

- Top blade may be lowered gradually, stopping at any point, to a position just above plate surface.
- Allows time for careful positioning of bend lines under the blade.
- Blade will automatically return from its present lowest position.
- Blade upper position can be controlled by limit switches, enabling repeat bends to be made at greater speed and improving safety by minimising blade clearances.
- Blade can be automatically held at its lowest position for pre-determined periods up to one minute, a necessary feature in coining operations.
- Materials can be pressed under the blade at any position along its length.
- ‘Inch up’ bottom raises beam from any position, blade does not have to complete a full cycle and jamming is impossible.
- Bottom beam may be tilted slightly for use in ‘fade out’ or conical pressing.

Curved and conical work

Curved plates are produced by a series of small bends across the plate (not as sharp as 90 degrees). Best results are obtained by pressing on equally spaced lines, with the same pressure. If more bend is required, it can be obtained by either increasing pressure and repeating, or pressing midway between bend lines with the same pressure. It is unwise to change pressure part way through a bend.

Curved and conical work

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In one-off bends, continued pressing between previous bend lines will often produce the necessary final radius with a very smooth finish. For production work the sequence should be worked out to provide a satisfactory result with minimum presswork.
Hot pressing

Furnace

These are a major part of the equipment required to hot form plates.

Most plate-heating furnaces are simply a rectangular steel casing with a large door in one end. They are still all lined with fire-brick, the roof often being arched as shown (See Fig 7.42). If it is fired from one side only, the roof may slope steeply to deflect the hot gases.

Photographs courtesy of Furnance Technologies

Fig 7.42 – Plate-heating furnace
Chapter 7 – Form, shape, bend (parts 1, 2 and 3)

The door is a steel casing lined with fire-brick, guided up and down by slide rails and lifted either by hydraulic hoists or by hand, assisted by counter weights. It is fitted with inspection peep holes.

Photograph courtesy of Furnance Technologies Pty Ltd

Fig 7.43 – Furnace door

The heating medium is oil or gas with the burners placed in the sides as shown in the illustration.

Plates are lifted into the furnace by crane, on a long counter-balanced lifting fork. They are landed on steel pads placed on top of fire-brick stools, thus allowing heat to circulate under the plate. The steel pads prevent fire-brick particles sticking to the plate and damaging the dies during the pressing operations.

Furnace temperatures are measured by thermocouple and indicated by graduated dials.

Photograph courtesy of Furnance Technologies Pty Ltd

Fig 7.44 – Furnace temperature gauge
Procedure
Hot pressing is a specialised process in which procedures vary considerably according to the work being done. One common application is the production of dished and flanged heads. Heads in their various shapes or forms are manufactured primarily as economical closures for cylindrical shells for the storage of gases or liquids under pressure, vacuum or atmospheric conditions.

It is generally accepted that the most practical standard shapes are torispherical and semi-ellipsoidal with the latter having the advantage of using thinner material for a given pressure.

Such heads are hot pressed to ensure consistency of dimensions and lack of forming stress in the finished head.

Dies used in forming heads
Fig 7.45 shows a simple arrangement for pressing flanged heads, but removal may be difficult.

Fig 7.45 – Pressing cylinder dished end
Activity

With reference to the various rolling machines described in this chapter:

- ask your lecturer to identify rolling machinery and types available in the workshop. The lecturer may also be able to demonstrate typical applications and the correct use of each particular machine.

Pay particular attention to the initial pinch set up requirements of this type of machine. Make note of the various methods and tools available for presetting and checking the ends of material prior to any rolling that is to be carried out on a pyramid type rolling machine.

- Ask your lecturer to identify the various types of presses available in the workshop in relation to the various types of presses available as described in this chapter. The lecturer may also be able to demonstrate applications and the correct use of each particular machine.

Pay particular attention to the selection of top and bottom tool combinations and the correct bottom tool opening or die ratio that should be used on the electro-hydraulic press. Pay particular attention to the set up procedure and the methods used to trial the operation before any proper action takes place.

These machines have the potential to seriously harm the operator. Make note of any hazards associated with the use of each machine and remember to use the recommended safety procedures and PPE when using each machine for assigned practice or project work.
Chapter 8 – Jigs and fixtures

Jigs and fixtures are used in metal fabrication, welding, or engineering works for a variety of purposes. They may be used where quantities of similar parts are to be manufactured and are often used to improve accuracy in assembly of component parts of a finished product. Fabrication and welding workshops make extensive use of jigs and fixtures, and it has been found that efficient use of them enables a marked increase in production, improved quality and reduced costs.

Jigs take many forms, some being well-known devices used in normal engineering workshop practice such as marking templates, with others being designed specifically for use in positioning the work as well as holding it for drilling, fabrication or welding operations. Some are simple workshop tools in various forms; others are complex and incorporate various clamping devices and mechanisms. Whatever the form, they have a number of common functions and features.

In this chapter we will look at the following.

- Jigs and fixtures
  - types of jigs
    - drilling jigs
    - assembly and welding jigs
  - designing and making a jig
- Activity.
Jigs and fixtures defined

A jig is a tool or device that serves the purpose of holding and properly locating a component part or piece of work while certain operations are carried out. Jigs may contain guides, locators, clamping devices and supports. Jigs are often used to improve consistency, quality, or improve productivity.

A fixture is a temporary device that only holds the work while operations are performed, for example a cleat fixture or tacking fixture that is manually placed on the job to enable the part to be located properly.

Jigs and fixtures have many points in common. Because it is often difficult to differentiate clearly between them, it is intended to proceed as if the two terms are identical. Thus, from a fabrication or welding viewpoint, we may redefine jigs and/or fixtures as those devices used to assist in marking, aligning or holding component parts in place prior to any operations being performed, thus relieving the operator from subsidiary manipulations and alignments and enabling them to concentrate on the actual operation.

Their use can have a marked effect on reduction of cost, improved accuracy, and greater consistency and speed of the work. For repetition work they are particularly valuable, and should be used wherever possible.

Types of jigs

An almost infinite number of different jigs are used in the metal fabrication or welding industry. However, for the purpose of this unit they can be categorised as either:

- drilling jigs
- assembly jigs
- welding jigs.

Drilling jigs

Drilling jigs are useful where a number of similar items require holes to be drilled accurately. When designing a drilling jig, the following factors should be considered:

- clamping of the work
- support of the work against the forces exerted by the drilling operation
- locating of the work to provide dimensional accuracy
- guiding of the tool, if required
- provision for swarf removal
- ease of operation.
Clamping

Clamping stresses should be sufficient to hold the work firmly but not excessive so as to produce distortion of the work. The clamping forces should be directed so that the work is held properly and will not rise from the supports.

![Fig 8.1 – Clamping force (vice)](image)

Support

Adequate support must be provided to withstand the forces exerted by the drill on the work piece. Supports should be placed close to the drilling operation to prevent distortion of the work piece and subsequent inaccuracy or drill breakage. This will also reduce vibration and drill ‘chatter’.

![Fig 8.2 – Support](image)

Locating

The jig must allow the work piece to be accurately and easily placed in position. This often requires locating stops to be incorporated in the jig so that the work is located in at least three places. The work piece should be positively located, and not free to slide or rotate in any direction.

![Fig 8.3 – Locating](image)
**Drill guiding**

If required, the drilling jig can incorporate a drill plate to locate the drill and guide it during the drilling operation. Hardened steel bushings can be used in the drill plate with an inner diameter just enough larger than the drill to be used. This allows the drill to turn freely but not drift appreciably. The bushings should be long enough so that the drill is guided close to the surface where it will start drilling.

**Swarf removal**

An essential feature of a drilling jig is the provision for swarf removal, particularly from locating surfaces. Fig 8.4 illustrates how insufficient clearance between the end of a drill guide and the work piece can prevent the swarf from escaping whereas too much clearance may not provide adequate drill guidance and can result in broken drills.

![Fig 8.4 – Importance of proper swarf clearance](image)

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<tr>
<th>Term</th>
<th>Definition</th>
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<tr>
<td>swarf</td>
<td>the debris or waste of metal from drilling operations, such as shavings</td>
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</table>
Examples of drilling jigs
The following are examples of successful drilling jigs and are included to illustrate the variety of devices that can be employed.

**Box jig**

**Plate jig**

**Flange drilling jig**

Fig 8.5 – Examples of drilling jigs
Plate jigs
A plate jig is one of the simplest types, consisting only of a plate that contains the drill bushings, and a simple means of clamping the work in the jig, or the jig to the work. In the latter case, where the jig is clamped to the work, it sometimes is called a clamp-on jig. Such jigs are frequently used on large parts, where it is necessary to drill one or more holes that must be spaced accurately with respect to each other, or to a corner of the part, but that need not have an exact relationship with other portions of the work.

Box jigs
Box jigs are very common, deriving their name from their boxlike construction. They have five fixed sides and a hinged cover or leaf. Usually, the drill bushings are located in the fixed sides to assure retention of their accuracy.

Assembly and welding jigs

Assembly jigs and welding jigs have many common features and it is often difficult to differentiate between the two. An assembly jig may have the purpose of simply placing the components of the job in their correct position and after tack welding the work is removed from the jig for welding. On the other hand many, assembly jigs are designed so that the work can be welded in the jig.

The following discussion relates mainly to assembly jigs but many of the points under discussion could apply equally to welding jigs.
The principle purpose of any jig or fixture is to make it easy for the operator to obtain a quality job with improved duty cycle. In addition to positioning for the most convenient welding position (i.e., downhand or flat welding), the jig may also be required to hold the parts in correct relative position and alignment. Thus we may state that the most important duties of an assembly jig are:

- the location of individual parts to provide dimensional accuracy
- holding parts in correct location during operations
- positioning of the work for tacking or welding
- control of distortion.

**Terms**

**Locating**

Setting or positioning and holding a number of parts in the correct relationship for welding, to produce a given size or shape of finished component.

**Holding**

Clamping the parts together at the joints so that the essential dimensions are maintained. Holding to restrict movement or distortion.

**Positioning**

Making it possible to arrange the work so that welding can be done in the most convenient position.

**Control of distortion**

Another essential of certain types of welding jig is to provide in its construction for the dissipation of welding heat and to minimise distortion. This applies especially to sheet metal work. A material such as copper may be introduced as a form a backing to act as a heat conductor or ‘chill bar’. The backing bar may be flat and simple, or have a machined groove that permits the escape of welding gases and assists in obtaining full penetration.
Designing and making a jig

Jigs and fixtures can be relatively simple in construction and are often made from scrap materials, therefore they do not usually involve the expense that is normally associated with tool room products where extreme accuracy is essential. As they may also be very complex, it is necessary to consider carefully whether their cost can be justified, having regard to the number of fabrications which are to be assembled or welded and the other methods of distortion control that are available.

Wherever possible, the jig should be designed and used for the complete operation, not just for tack welding. But there are times when quickly mocked-up purpose made jigs can be used economically for tack welding sub-assemblies together, and these would be subsequently welded in a final welding jig or on a positioner.

Locating and clamping accessories

Associated with jigs and fixtures are a number of devices for locating and securing the components to be welded. These may take the form of stops, wedges, cleats, clamps, restraints, toggles, etc (see Fig 8.7). The choice of the type of device will of course depend on the shape of the parts, the number and position of parts to be held at one time, and even on the number of objects to be fabricated.

Fig 8.7– Locating and clamping accessories
The simplest possible device should always be selected, bearing in mind that the criteria should be ease and speed of clamping and releasing, firm holding of parts and sufficient flexibility of design for it to be used for other operations.

Screw operation is relatively slow and should be avoided wherever possible, but it provides considerable power. Locking is generally positive so that slip of the parts is avoided. Movement of the screw should be controlled by a hand wheel or spider, not by spanners that can be easily mislaid.

Lever operation is quick, but the power exerted is small and an additional means of locking must be provided.

Toggle lever mechanisms have the advantage of quick, powerful and self-locking action, and should be used wherever possible. They are cheap, and will clamp a wide size range of component if provided with adjusting screws. They can be made in a variety of shapes to suit almost all conditions of fixing and location.

Many of the simplest jigs have no moving mechanisms, i.e., parts are aligned and held in position by means of bolts and dog clamps, tapered pins, or dogs and wedges.

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**Fig 8.8** – (a) bolts and dogs, (b) wedge – pin method, and (c) dog and wedge for fairing plate
Activity

Consult your lecturer and ask them to help you to design and build jigs for project work. Look at the range of possibilities available when jigs are produced.
Chapter 9 – Steel structures (parts 1, 2 and 3)

Steel is the most commonly used metal in the frame or skeleton of many buildings and structures. Strong, light weight rolled steel sections or fabricated steel sections are the preferred choice of engineers and, when combined with good design, can be used in all sorts of situations. Modern workshop techniques can produce steel frames or structures that are low in cost, easy to transport, and easy to assemble on site.

Some basic designs that are used in fabricated metal framework buildings are:

- cage frame (columns and beams)
- trussed roof (trusses on columns)
- rigid frame (portal frame)
- grid frame (space structure).

In this chapter we will look at the following:

- Steel structures
  - Part 1 – Cage frame structures (columns and beams)
    - Building components
  - Part 2 – Trussed frame structures (trusses on columns)
    - Truss systems
  - Part 3 – Rigid frame (portal frame)
    - Building construction
Steel structures

Part 1 – Cage frame (columns and beams)

This simple design is based on the principle of supporting girders or beams fixed at their junctions with stanchions or columns. With close column spacing, material costs are low and fabrication, transport and site erection aspects are simple. Wide column spacings or long beam span distances mean increasing material size and overall associated costs.

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>girder</td>
<td>heavy construction support member</td>
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<tr>
<td>beam</td>
<td>horizontal load bearing member</td>
</tr>
<tr>
<td>stanchion</td>
<td>heavy construction vertical member</td>
</tr>
<tr>
<td>column</td>
<td>vertical load bearing member</td>
</tr>
<tr>
<td>span</td>
<td>the distance between columns or supports</td>
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The cage frame is typically used for multi-level buildings and industrial plants, but is adaptable to various requirements.

Fig 9.1 – Cage frame (columns and beams)
Part 2 – Trussed roof (trusses on columns)

The trussed roof design is simple, but needs to have columns placed on the floor area at regular intervals. When compared to cage frames, an increase in column spacing or span distance is possible. The number of trusses required for a building depends on the **pitch** or spacing of trusses, which is decided by purlin types and roofing materials used and the area of covered space needed. Clever design can make trussed roof buildings suitable for a large number of applications and very economical in material and labour costs.

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<tr>
<th>Term</th>
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<tbody>
<tr>
<td>pitch</td>
<td>spacing between trusses (bays)</td>
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</table>

Trusses are typically used for single storey type buildings such as sheds, garages, small and large workshops, warehouses and factories.

Fig 9.2 – Trussed roof (trusses on columns)

Fig 9.3 – Grid frame (space structure)
Part 3 – Rigid frame (portal frame)

The modern rigid frame consists of members that are connected directly together. The floor is often used as a tie and this design responds to the demand for cheap large areas of covered single level floor space.

<table>
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<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>tie</td>
<td>any member in tension (bracing)</td>
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</table>

The portal frame is used for large open floor space workshops, warehouses and factories.
Part 1 – Cage frame structures

This section introduces you to the fabrication techniques and terms associated with the construction of cage frame structures, in particular structures fabricated from universal columns (UC) and universal beams (UB).

Cage frames are structures that are used as the skeleton or support system for buildings. They are commonly used for city buildings and process plants.

Building components

Footing

Footings generally consist of concrete blocks designed to take the weight of the building. They may be separate to, or integrated into the floor. Threaded holding down bolts are usually set into the concrete. The column base is lifted onto the holding down bolts and supported at the right height by packing. The column is then plumbed vertical as the holding down bolts are tightened. Once the whole structure is erected, plumbed and secure, the space between the column base and the footing is filled with grout to firm up the structure and help support the building. A minimum 25 mm is required for the grouting.
### Chapter 9 – Steel structures (parts 1, 2 and 3)

**Glossary**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>footing</td>
<td>support or fixing point for column (foundation)</td>
</tr>
<tr>
<td>grout</td>
<td>a mortar type cement base mix between column and footing</td>
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</tbody>
</table>

**Fig 9.5 – Typical column footing**

**Holding down bolt**

The holding down bolt may be a simple hook bolt, a made up cage assembly, or some other design.

**Fig 9.6 – Hook bolt and cage assembly**
Because the base plate needs to slip over the holding down bolts when the column is being erected on site, a jig is often used to assemble or align the holding down bolts or the cage.

**Column bases**

Column bases, or base plates, are used to attach a column to the footings and are also designed to spread the compressive load over a larger area. A base plate hole is allowed to be bolt diameter plus 3 mm for ease of assembly on site and because they are generally large bolts. Column bases may be plain or gusseted.

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<thead>
<tr>
<th>Term</th>
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<tr>
<td>base plate</td>
<td>attaches column to footing</td>
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**Plain** (or slab type) base plates are the most common type used, because they require minimal time to fabricate and weld onto the column. The slab base uses a relatively thick plate for stiffness.

![Plain base](image)

**Fig 9.7 – Plain base**
Gusseted base plates are used on smaller sections and where thinner base material is used, as in lightweight designs. Gusseted base plates may also be used where higher strength or stiffness is required (there is a higher fabrication cost).

Fig 9.8 – Gusseted base

**Cap plate, connecting plate and shear plates**

A cap plate is usually a plate that is positioned at the top of a column to enable other components to be fastened to the column.

Fig 9.9 – Cap plate, connecting plate and shear plates

A connecting plate or cleat (there are many different designs that may be used) is used to make a join or connection between components in a structure, or simply to join one member to another member.

A shear plate is positioned under a horizontal load bearing member to provide support during assembly and to assist in taking up the load.
Columns/stanchions

Columns are the vertical structural load bearing members of a steel building. The load on a column is compressive. Rolled steel universal columns are nearly always used in a cage frame building because of their superior compressive strength and resistance to side forces. The shape of universal columns also allows for easier connections for beams.

Lightly loaded columns, or those used in simple structures, are often made up from angle or hollow steel sections such as pipe or square or rectangular hollow sections.

Fig 9.10 – Vertical column

<table>
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<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>connecting plate</td>
<td>a plate that joins components together</td>
</tr>
<tr>
<td>shear plate</td>
<td>a supporting plate for a horizontal member</td>
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<th>Term</th>
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<tr>
<td>stanchions</td>
<td>an American term used to describe heavier section columns</td>
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</table>
Beams/girders

Beams are simply horizontal structural members that are required to carry a load perpendicular to their longitudinal axis.

![Simple Beam](image)

**Fig 9.11– Simple beam**

Rolled steel universal beams are ideally suited to the task of supporting this type of load, because of their greater depth of section in the web. They are also the most economical sectional shape to use, but other section shapes can be adapted or modified to suit.

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<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>web/gusset</td>
<td>the plates used to connect various members</td>
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Some designs may require a beam to carry a higher load or cover a greater span than the commercial products allow. A beam may be required to perform some other task or provide visual or aesthetic impact.

When standard rolled steel products are not available in the size or section required, fabricated or welded beams and girders are used.

**Fabricated beams**

Fabricated beams can be made up from a whole range of rolled steel sections. Some sections can be used in modified situations, or two or more standard sections can be used to form a compound member that meets design requirements. Beams may also be made up from plate welded together.

Examples of fabricated beams are:

- tapered beams
- compound beams
- box girders
- hybrid beams
- castellated beams
- vierendeel beams
- welded beams.
Tapered beams

Tapered beams are made up from standard rolled steel sections that are cut at an angle and then welded together to form a tapered beam. The depth of a tapered beam is greater in the centre where it is needed the most, and reduced at the points where the load is less.

This design requires some time to fabricate but provides a reduction in overall mass of the beam.

Notice the absence of a lower flange on the beam in the diagram shown. The lower flange is in tension and does not require flanges when lightly loaded, but they may be easily provided if required by welding on flat bars.

![Fig 9.12 – Tapered beam](image)

Castellated beams

Castellated beams are made up from standard rolled steel sections that are carefully cut and reassembled in a way that will allow an increase in the depth of section with no increase in mass.

A beam’s ability to support a load or cover distance is linked to its depth of section. This design provides a simple increase in the section depth.

The castellated beam requires considerable time and effort to produce, but provides superior strength or span capabilities over the standard rolled steel section.
Chapter 9 – Steel structures (parts 1, 2 and 3)

Compound beams

Compound beams are made up from combinations of various standard rolled steel products, welded together to provide the desired profile and properties.

Fig 9.13 – Castellated beams

Fig 9.14 – Angle bar and flat bar beam

Fig 9.15 – Channel and flat bar beam
Fig 9.16 – Compound beam using plate or channel

Fig 9.17 – Channel and plate beam

Fig 9.18 – Channel and angle beam
Many other combinations of rolled steel sections may be possible, or be used to form up compound beams.

Vierendeel beams

Vierendeel beams may incorporate modified steel sections or rolled steel plate in fabricated beams that are used mainly for load bearing situations, or for support beams in structures such as buildings or bridges.

The design provides high strength with low mass. The openings in the web reduce weight and allow for service facilities such as ducting, electrical wiring and pipe work to pass through the beam.

Fig 9.19 – Vierendeel beams
**Box girders**

Box girders are made up from rolled steel plate and can be strengthened using stiffeners or additional sections. They are often used in special applications, or where high strength is required such as in crane booms and overhead cranes, or long span bridges for road or rail.

![Diagram of Box Girders](image)

**Fig 9.20 – Fabricated box girders (a) and (b)**

**Welded beams**

Welded beams (WB) and welded columns (WC) are made by BHP. These are now readily available in much larger sizes than standard universal beams and columns. In many cases, these items are supplied by BHP in knock-down form and only require local assembly and welding.

![Diagram of Welded Beams](image)

**Fig 9.21 – Welded beams**
Welded columns

Lengths can be supplied from a minimum of 6 metres to a maximum of 30 metres with a length tolerance of +/- 2 mm. Other lengths may be available.

In the popular sections of 700 WB, 800 WB, 900 WB and 350 WC, standard lengths will be offered in 12, 15 and 18 metres.

![Fig 9.22 – Welded columns](image)

Hybrid beams

Hybrid beams are fabricated from different strength materials consisting of high strength steel flanges welded to a lower strength web plate. The high strength steel used for the flanges provides higher strength for the members in compression and tension. The plain carbon steel web provides adequate separation and shear strength.

The use of high strength materials in a hybrid beam produces a stronger beam, when compared to a similar section size in plain carbon steel.

However, care needs to be taken in the cutting and welding of hybrid beams because of the effects of heat and poor weldability of some of the alloy steels used.

![Fig 9.23 – Hybrid beam](image)
**Strengthening and stiffening**

To meet design requirements, some beam sections may be strengthened in the flange, web or across the section. The flanges may be strengthened by using thicker materials or by welding additional thickness on to the flanges.

Stiffeners may be added to provide resistance to loads or to prevent twisting or buckling of the flanges.

**Expansion joints**

Where structural steelwork such as beams or girders are subject to temperature fluctuations or stress, an allowance for movement can be made by providing an expansion joint in the critical area.
Splices and splicing

When structural sections need to be lengthened, a join or splice joint is required. Often a join may simply be required because the length of stock is not sufficient, or to reduce waste. An existing column or length or beam may need to be extended. Transport requirements may also require a join so the component can fit on to a truck.

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<tr>
<td>splice</td>
<td>joint in column or beam</td>
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Joints must be free from misalignment, twist or built in stress. Joins can be made in the workshop or on site. Various methods are used to make the join or splice. Joins or splices may be made in a single plane.

**Fig 9.26 – Single plane splice**

Joints may also be through a number of planes as shown. These are used to increase weld area but this is not necessary if welding is done correctly.

**Fig 9.27 – Multiple plain splices**
The join or splice can be either welded or bolted:

- **Welded joints** are simple and strong, they may be completed in the workshop where all the required facilities are available. Site welded joints are often used but require more skill in alignment and weld performance than workshop joints.

- **Bolted joints** require more component parts and labour than a welded joint. Because they can be made up in the workshop this is a minor fault. Bolted joints are more suited to site works because less equipment and skill is required to assemble the component parts. Bolted components may also be broken down into parts easily.

**Column splices**

**Welded type**

Welded type column joins or splices usually consist of butt or fillet type joints designed to take compressive loads.

![Fig 9.28 – Welded equal sections](image)

![Fig 9.29 – Welded unequal sections](image)
Bolted type
Bolted type column splices use splice plates to hold the parts together and in line. The ends of the sections may be butted together to take the load. Alternatively, the ends of the sections may be assembled with a gap and the joint may use a bolt bearing or friction grip type design.

Fig 9.30 – Bolted equal sections

Fig 9.31 – Bolted unequal sections

Welded/bolted splice
A join or splice can be made up using a combination of welding and bolting and this type of joint is by far the most common type used for construction of a wide variety of structures.

It is good practice to assemble the full joint in the workshop and thus allow easy alignment of parts, match drilling of holes and also the performance of any welding operations required.
The join is then broken and easily reassembled on site using the bolting technique.

**Fig 9.32 – Welded/bolted splice**

**Gauge lines**
Gauge lines are parallel to rolled steel section centre lines or edges and used to determine where holes are positioned.

Universal columns or beams usually have two holes across the flange. These are placed about the centre line.

Channel and angle section gauge lines are measured from the heel to the centre line of the holes. The distance tends to vary, depending on section size.

**Fig 9.33 – Gauge lines**

An attempt has been made to standardise beam and column gauge lines at 140 mm, 90 mm and 70 mm.
Centroids

Centroids are used to depict a central stress point (not the centre of gravity point) on structural steel section. These are used for design and for marking out points on a layout.

Fig 9.34 – Centroids
Centroid lines on symmetrical rolled steel sections are already on the centre line intersections.

On structural steel sections such as angle or channel, the centroid may be well away from the centre lines and can be found by referring to manufacturer’s tables.

OneSteel ‘Hot rolled and structural steel products’ is a ready reference source for centroid line offsets and gauge line distances.

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<th>Web thickness</th>
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Table 9.1 – Centroids

**Structural connections**

Cage frame structure joints can be of the ‘rigid’ or ‘simple’ design. The difference in the structural joint types can be easily explained when the complete structure and the way in which the joints perform is examined closely.

In a rigid structure, each connection is of a type that prevents any beam rotation or movement. The joint thus contributes to the overall stiffness of the structure. In a rigid cage frame structure, some form of additional stiffening or bracing is not usually required.

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In a simple structure, each connection is flexible and some movement at the connection is possible. The simple cage frame structure needs to have some form of additional stiffness or bracing to prevent excessive movement.

Some examples of cage frame structure beam to column connections and beam to beam connections are shown on the following pages.

Remember, these connections may be required for either rigid or flexible type structures.

The connections required can also be achieved by using welded, bolted or welded/bolted type joints.
Fig 9.37 – Corner beam to column

Fig 9.38 – Beam to beam
# Activity – Part 1 – Building components

![Universal Beam Diagram](image)

**Extract from OneSteel Hot Rolled and Structural Steel Products**

**Universal Beam – Properties and Dimensions**

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Table 9.2 – Universal beam – extract from OneSteel
### UNIVERSAL COLUMN

**EXTRACT FROM ONESTEEL HOT ROLLED AND STRUCTURAL STEEL PRODUCTS**

**UNIVERSAL COLUMN – PROPERTIES AND DIMENSIONS**

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*Table 9.3 – Universal column – extract from OneSteel*
### Table 9.4 – Parallel flange channel – extract from OneSteel

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### TAPERED FLANGE CHANNEL – PROPERTIES AND DIMENSIONS

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Table 9.5 – Tapered flange channel – extract from OneSteel
### EXTRACT FROM ONESTEEL HOT ROLLED AND STRUCTURAL STEEL PRODUCTS

#### TAPERED FLANGE BEAM – PROPERTIES AND DIMENSIONS

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Table 9.6 – Tapered flange beam – extract from OneSteel
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Table 9.7 – Equal angle A – extract from OneSteel
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## EXTRACT FROM ONESTEEL HOT ROLLED AND STRUCTURAL STEEL PRODUCTS

### UNEQUAL ANGLE – PROPERTIES AND DIMENSIONS

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Table 9.9 – Unequal angle – extract from OneSteel
Part 2 – Trussed frame structures

This section introduces you to the fabrication of roof structures, in particular roof trusses fabricated from circular hollow sections (CHS), rectangular hollow sections (RHS), channel (ASC), or rolled steel angles (ASA and ASUA).

Roof trusses are simply steel structures designed to carry a load or span a distance. They are commonly used for the roofing of sheds, workshops, factories and warehouses. The design can be varied to fit the purpose. For example, the Sydney Harbour bridge is simply two trusses side by side, held together by cross, vertical and diagonal bracing.

Truss systems

Roof trusses are mostly triangular in shape. The three most common roof truss designs are:

- Howe truss
- Pratt truss
- Warren truss.

Fig 9.39 – Parts of truss on columns
Howe truss
This truss has a centre, or king post and diagonal bracing that slopes outwards from the bottom chord.

Pratt truss
This truss has a centre, or king post and diagonal bracing that slopes outwards from the ridge.

Warren truss
This truss has no king post or vertical members.

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<td>bottom chord</td>
<td>the principal tension or bottom member</td>
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<tr>
<td>ridge/apex</td>
<td>the top point or intersection of top chords</td>
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Alternative roof truss system

Grid frame (space structure)
The grid frame or space frame system is made up of flat or three-dimensional structures or modules consisting of compression and tension members. The joints are complex and often make use of cast steel joiners or ‘nodules’.

The resultant structure is light and rigid and can be made to individual situations.

This design can be easily erected on site by semi-skilled labour. It is often used for large areas where columns would interfere with the floor space or for one-off situations such as concert halls, stadiums and shopping centres.

![Fig 9.43 – Grid frame (space structure)](image)

Roof truss configuration

Roof trusses are mostly assembled in basic configurations such as those shown previously or as variations such as:

- saw tooth trusses
- parallel chord trusses
- monitor trusses.

Saw tooth trusses

These trusses are often connected to parallel chord trusses, in a design that faces the apex into the sun known as ‘northern lights’.

![Fig 9.44 – Saw tooth truss](image)
Parallel chord trusses
This is a Howe design parallel chord truss, note how diagonal bracing is now in tension.

![Fig 9.45 – Parallel chord truss](image)

Monitor truss
This truss is a small truss that is bolted or welded over the ridge or apex of the main truss to allow for ventilation or light in workshops.

![Fig 9.46 – Monitor truss](image)

Roof truss construction
Roof trusses are usually made up of either tension or compression members, fastened together in a series of triangles. Trusses can be made up one at a time on a layout derived from member centroid lines, but this method is slow and labour intensive. Where a number of similar trusses are required, a ‘master truss’ is made up from the layout and then turned into an assembly jig for accurate assembly and welding of the required number of trusses.

Trusses can be constructed using any of the various rolled steel sections and shapes. Steel angle is commonly used for light trusses because it is easy to join the component parts together.

The following diagram shows the simple square cut and fillet weld connections used for light trusses constructed using steel angle.
Hollow sections such as circular hollow sections or square or rectangular hollow sections are preferred for use in trusses where strength is required. This is because hollow sections have a high resistance to bending under the compressive or side loadings found in trusses.

The use of hollow sections in roof trusses can be a disadvantage when the problems associated with joining the various component parts together are taken into account.

**Tubular connections**

The main problem encountered when working with hollow sections as used in truss frames is the connecting together of the various components. These connections can be considered as being of the welded or bolted type.

**Welded tubular connections**

Welded connections are commonly used to join the component parts of a truss, particularly on the branch connections. The ends of the circular hollow sections must be prepared for welding and the following examples are often used.
Free cut
Only suited to light construction where the branch pipe is smaller than the main tube.

Fig 9.49 – Free cut

Flattened
Only suited to light construction. Cold sheared or cropped pipes are often used in this type of connector, however it is recommended that fully flattened pipes should be worked hot.

Fig 9.50 – Flattened
Crimped/free cut

Suited to medium construction. Care should be taken to ensure the seam is not on the crimped edge and the pipe is not crimped to less than $\frac{2}{3}$ of the diameter of the pipe.

![Figure 9.51 – Crimped/free cut](image)

Profiled

Suitable for heavy construction. This method of construction is best where full strength joints are desired.

![Figure 9.52 – Transition of welds in branch connection](image)

Knowledge of parallel line development methods for set on branch pieces such as those found in fabrication cylinders is useful, because a pattern for the profiled joint is often required.
Bolted tubular connections

Bolted connections in truss systems are reserved for where there is a join or connection to another part, or for transport or site erection considerations.

Bolting has advantages over welding, especially on site where crane hire, erection time and equipment requirements are lower and less skill is required. In such situations, the provision for bolting sometimes requires the use of clever design, especially when hollow sections are involved.

A common method of joining or making connections to hollow sections is to either flatten the hollow section, or to utilise plates or angle section for the allowance of bolting. Some typical examples are shown in Fig 9.53.

![Flattened](image1)

![Plate attachment](image2)

![Slotted](image3)

![Angle attachment](image4)

**Fig 9.53 – Bolted tubular connections**

Truss shoe

Another problem encountered when using bolted connections in tubular construction trusses is the area where a truss is to be bolted to the top of the column.

The bolted connection occurs at or near the intersection of the top and bottom chord and can become quite complicated. The connection plate at this point is known as a truss shoe, as shown in Fig 9.54.
Columns
Columns are the vertical load bearing members of any steel building.

Lightly loaded columns (or those used in simple structures such as small or medium size buildings) are often made up from angle or hollow steel sections such as pipe, or square or rectangular hollow sections (see Fig 9.58 (a)).

Purlins and girts
The choice of material used for roof purlins or side wall girts depend on a number of factors. Timber may be chosen for aesthetic reasons, although its use is restricted to small span designs.

Steel is now the most common material used for purlins or girts, as steel allows the designer or engineer to utilise a much greater span or distance between columns or trusses.
The two most common steel sections used consist of C and Z sections.

C Section purlin

Z Section purlin

Fig 9.55 – Purlins and girts; C section purlin and Z section purlin
Chapter 9 – Steel structures (parts 1, 2 and 3)

Activity – Part 2 – Truss systems

Structural Tube - Pipe CHS (plain end) Grade C350LO

Section: PIPE (C.H.S) PLAIN END
Grade: AS1163-C350LO

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Table 9.10 – Hollow sections – properties and dimensions
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Table 9.10 – Hollow sections – properties and dimensions (continued)
Chapter 9 – Steel structures (parts 1, 2 and 3)

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Table 9.10 – Hollow sections – properties and dimensions (continued)
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Table 9.10 – Hollow sections – properties and dimensions (continued)
### Table 9.10 – Hollow sections – properties and dimensions (continued)

<table>
<thead>
<tr>
<th>Size mm (d x b x t)</th>
<th>Painted</th>
<th>Allgal</th>
<th>15+ kg/m</th>
<th>Metres per Tonne</th>
<th>Lengths per Bundle</th>
<th>Lengths per Mini Pack</th>
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<tr>
<td>125 x 75 x 3.0</td>
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<td>6.0</td>
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<td>16.7</td>
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<td>14.2</td>
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<td>15</td>
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<td>21.4</td>
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Part 3 – Portal frame structures

This section covers rigid or portal frame structures, support columns and beams and typical connections used in these structures. It is not the intention of this section to go back over previous material related to various steel sections and typical uses.

Rigid frame structures, commonly referred to as ‘portal frame structures’, consist of columns and beams that are connected together with rigid joints designed to transfer the roof load to the columns. The floor is used as a tie to stop the load spreading the columns apart. Allowance or provision for crane rails can also be easily incorporated into the design. Portal frame structures have become the favourite choice of designers when large areas of floor space need to be covered, such as in warehouses, factories and shopping centres.

Building construction

Standardised portal frames

In the 15 m to 40 m span range, the portal frame is the most economical design to use. The portal frame structure may be made in a one-off batch to suit a particular site.

The most common method of making up portal frames is from standard component parts such as shop welded knee and apex joints. With this method of construction it is only necessary to provide variable lengths for the columns or beams to provide a wide range in spans and height. Some fabrication shops offer a range of these component parts for popular steel sections and sizes.

Component parts of the portal frame are usually fabricated in the workshop and then transported to the site to be assembled.
Bolted and/or welded
The assembly joint can be either welded or bolted and must be free from misalignment, twist or built in stress. Welded joints have the advantage of being simple and strong and may be completed in the workshop where all the required facilities are available. Site welded joints are more difficult but still result in strong joints.

The bolted joint requires more component parts and labour than a welded joint, but because they can be made up in the workshop this is a minor fault. Bolted joints are better on site because less equipment and skill is required to assemble the component parts that have been broken up for transport.

The following pages are used to depict the various component parts of portal frames and typical connections, bracing, purlins and girts.

There could be many variations to each example.

Typical portal frame components and connections
Columns
Columns are the vertical load bearing members of a steel building. In a portal frame, the column is subject to bending moments or forces because of the design. The portal frame design also allows easy provision for crane rail support. The portal frame column is often made up from universal beam or could be fabricated from various rolled steel products, as shown in Fig 9.58.
Fig 9.58 – Column (a) universal beam column, and (b) fabricated column

**Rafter**

The rafter is a near horizontal, load bearing component of the portal frame that is used to take up the weight of the roof material through the purlin and purlin cleats. The rafter is also subject to bending moments or forces, because of the design of portal frames.

Rafters may be separate components that are bolted or welded into place, or they may be built in during manufacture of a portal frame. Rafters generally have a greater depth than width and when required for portal frames, are mostly made up from universal beams.
Apex joint

The apex joint of a portal frame can be either bolted together or welded and these operations may be performed in the workshop or on site. The joint may even have additional stiffening to take up the load of the structure.

Fig 9.59 – Rafter

Fig 9.60 – Shop welded standard apex with bolted splice joints
(a) bolted, (b) welded, and (c) spliced
Knee joints
The knee joint is no more or less critical than any other joint in the portal frame and construction methods are similar.

Fig 9.61 – Shop welded standard knee with bolted splice joints
(a) bolted, (b) welded, and (c) spliced
Bracing

Bracing is typically made up from flat bar, angle or pipe and is used to prevent movement or twist in the side walls, end walls or roof.

![Typical wall and roof bracing](image)

**Fig 9.62 – Typical wall and roof bracing**

Purlin or girt

The choice of material used for roof purlins or side wall girts depends on a number of factors. Timber may be chosen for aesthetic reasons, although its use is restricted to small span designs. Steel is now the most common material used for purlins or girts, as it allows the designer or engineer to utilise a much greater span or distance between frames. When greater span distances are combined with an increase in pitch or distance apart, this can provide a reduction in the mass of the roof. A reduction in the mass of roof material means the whole design can be downsized and this provides a further reduction in material and costs.

The two most common steel purlin sections used consist of C and Z sections.

![C and Z section purlins](image)

**Fig 9.63 – (a) C section purlin, and (b) Z section purlin**

Gauge lines (‘g’ for holes in purlins are standardised at 38 mm, 89 mm and 127 mm.)
Standard connections – C and Z sections

Fig 9.64 – (a) section, and (b) cleats

<table>
<thead>
<tr>
<th>C or Z section size</th>
<th>‘g’</th>
<th>‘b’</th>
<th>‘y’</th>
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<tbody>
<tr>
<td>102</td>
<td>38</td>
<td>45</td>
<td>105</td>
</tr>
<tr>
<td>152</td>
<td>89</td>
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<td>155</td>
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<tr>
<td>203</td>
<td>127</td>
<td>50</td>
<td>200</td>
</tr>
</tbody>
</table>

Table 9.11 – Gauge line
Activity – Part 3 building construction

With reference to the various components in steel structures.

- Layout a truss on the workshop floor using appropriate tools.
- Construct a truss shoe.
- Using tubular section construct at least 3 methods of joining such as free cuts, flattened and crimped.
- Erect a column given the holding down bolts (footing).
# Appendix

## Metals and fabrication competency mapping

<table>
<thead>
<tr>
<th>Book title</th>
<th>Chapter title</th>
<th>Comp code</th>
<th>Competency title</th>
<th>Full partial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fabrication</td>
<td>1. Introduction to trade and awards</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2. Tools of the trade (hand)</td>
<td>MEM 18.1C</td>
<td>Use hand tools</td>
<td>*</td>
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<tr>
<td></td>
<td>3. Tools of the trade (power)</td>
<td>MEM 18.2B</td>
<td>Use power tools/hand held operations</td>
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<tr>
<td></td>
<td>4. Job planning</td>
<td>MEM 14.4A</td>
<td>Plan to undertake a routine task</td>
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<tr>
<td></td>
<td></td>
<td>MEM 14.5A</td>
<td>Plan a complete activity</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.10B</td>
<td>Apply fabrication, forming and shaping techniques</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.11C</td>
<td>Assemble fabricated components</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 12.6B</td>
<td>Mark off/out (general engineering)</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 12.7C</td>
<td>Mark off/out structural fabrications and shapes</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td>5. Mechanical cutting</td>
<td>MEM 5.5B</td>
<td>Carry out mechanical cutting</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.10B</td>
<td>Apply fabrication, forming and shaping techniques</td>
<td>*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>MEM 5.11C</td>
<td>Assemble fabricated components</td>
<td>*</td>
</tr>
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<td></td>
<td>6. Methods of fastening (bolting)</td>
<td>MEM 5.11C</td>
<td>Assemble fabricated components</td>
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<tr>
<td></td>
<td>7. Form, shape and bending – Part 1 and 2</td>
<td>MEM 5.10B</td>
<td>Apply fabrication, forming and shaping techniques</td>
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<td>Chapter title</td>
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<td>---------------------------------------------------------------</td>
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</tr>
<tr>
<td>8. Jigs and fixtures</td>
<td>MEM 5.10B Apply fabrication, forming and shaping techniques</td>
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<td>*</td>
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<tr>
<td></td>
<td>MEM 5.11C Assemble fabricated components</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>MEM 12.6B Mark off/out (general engineering)</td>
<td></td>
<td>*</td>
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<tr>
<td>9. Steel structures – Part 1, 2 and 3</td>
<td>MEM 5.11C Assemble fabricated components</td>
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Fabrication

This resource is specifically designed to provide basic underpinning knowledge related to a number of competency units used in the Engineering Tradesperson Fabrication (Heavy) pathway across TAFEWA from January 2007. This pathway was specifically designed to meet the needs of the heavy metal fabrication industry after industry consultation and TAFEWA moderation sessions held in 2006. This pathway is also designed to be common across all colleges of TAFEWA (customisation to suit local conditions is however encouraged. The pathway meets the requirements and guidelines of the MEM05 Training Package.

Context of assessment

Assessors are reminded the individual units may be assessed on-the-job, off-the-job or a combination of both on and off-the-job. Where assessment occurs off-the-job, that is the candidate is not in productive work, then an appropriate simulation must be used where the range of conditions reflects realistic workplace situations.

Project work, integration

These units could be assessed in conjunction with mandatory units addressing the safety, quality, communication, mathematics etc. Units may also be assessed with other units requiring the exercise of the skills and knowledge.

Method of assessment

Assessors should gather a range of evidence that is valid, sufficient, current and authentic. Evidence can be gathered through a variety of ways including direct observation, supervisor’s reports, project work, samples and questioning. Questioning should not require language, literacy and numeracy skills beyond those required in this unit. The candidate must have access to all tools, equipment, materials and documentation required. The candidate must be permitted to refer to any relevant workplace procedures, product and manufacturing specifications, codes, standards, manuals and reference materials.

Consistency of performance

Assessors must be satisfied that the candidate can competently and consistently perform all elements of the units as specified by the criteria, including required knowledge, and be capable of applying the competency in new and different situations and contexts.
DESCRIPTION
This resource supports learners to develop intermediate-level skills and knowledge relating to a number of competency units used in the Engineering Tradesperson Fabrication learning pathway.

Topics covered include the following:
• Introduction to trade history
• Tools of the trade (hand)
• Tools of the trade (power)
• Job planning
• Mechanical cutting
• Methods of fastening (bolting)
• Form, shape, bend (parts 1, 2 and 3)
• Jigs and fixtures
• Steel structures (parts 1, 2 and 3)

The book is divided into separate chapters, each containing workshop-based activities that will provide opportunities for practice before assessment. Detailed graphics, technical drawings and photographs are provided throughout the book to support learners.

EDITION
2007

CATEGORY
Metals & Engineering

TRAINING PACKAGE
• MEM05