

# Trade of Metal Fabrication

Module 4:	Structural Steel Fabrication
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Unit 9:	Splice Joints
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	Phase 2
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## Document Release History

Date	Version	Comments
05/02/07	First draft	
01/03/07	Added 'Properties and Structure of Metals' section	
13/12/13	SOLAS transfer	

## Module 4 – Structural Steel Fabrication

### Unit 9 – Splice Joints

**Duration – 16 Hours**

**Learning Outcome:**

By the end of this unit each apprentice will be able to:

- Read and interpret drawing
- Fabricate a spliced universal beam joint
- Sketch and describe what happens to typical tension test specimen and sketch and explain a stress/strain curve for tension specimen

**Key Learning Points:**

<b>Rk Sk</b>	Marking out - cutting - assembling and welding/spirit level chalk line.
<b>Rk</b>	Identification of load indicating bolts and their applications. High strength friction grip bolts (H.S.F.G.).
<b>Rk</b>	Different types of spliced joints, bolted/welded.
<b>Sc Rk</b>	Properties of structural steel, elasticity - compressive and tensile strength. (For more information see Module 4 Unit 4).
<b>Rk Sc</b>	Tension testing of structural sheets - showing test specimens. (For more information see Module 4 Unit 4).
<b>M Rk Sc</b>	Plotting stress/strain curve showing yield point.
<b>Rk</b>	Areas where splicing is used/not used. (For more information see Module 4 Unit 4).
<b>M</b>	Revision of relevant mathematics.
<b>H</b>	Hazards of load failure - consequences.
<b>H</b>	Awareness of safety precautions/hazards associated with fabrication.
<b>P</b>	Communication, work planning, quality of work.

**Training Resources:**

- Apprentice toolkit
- Fabrication workshop and equipment
- P.P.E.
- Instructor demonstrations and lectures
- Handouts, notes
- Samples of tensile test
- Drawing equipment

**Key Learning Points Code:**

**M** = Maths      **D** = Drawing      **RK** = Related Knowledge      **Sc** = Science  
**P** = Personal Skills      **Sk** = Skill      **H** = Hazards

## Datums


### Total Runout

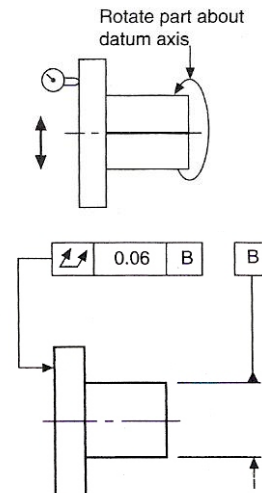
#### Case 1

##### *Product requirement*

The total runout must not exceed 0.06 at any point measured across the entire surface parallel to the datum axis.

##### *Drawing instruction*

**Note:** The symbol  means that the measuring instrument is guided across a theoretically exact surface true to the datum axis.



### Position/Datums

A positional tolerance controls the location of one feature from another feature or datum.

The tolerance zone can be the space between two parallel lines or planes, a circle, or a cylinder. The zone defines the permissible deviation of a specified feature from a theoretically exact position.

The tolerance value is the distance between the parallel lines or planes, or the diameters of the circle or cylinder.

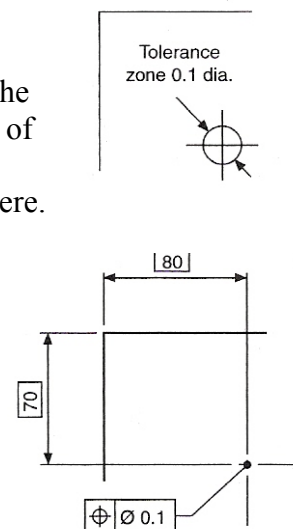
The theoretically exact position also incorporates squareness and parallelism of the tolerance zones with the plane of the drawing.

#### Case 1

##### *Product requirement*

The point must be contained within a circle of 0.1 diameter in the plane of the surface. The circle has its centre at the intersection of the two theoretically exact dimensions. If the point were to be located by three dimensions, the tolerance zone would be a sphere.

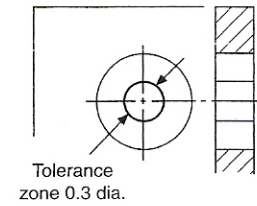
##### *Drawing instruction*



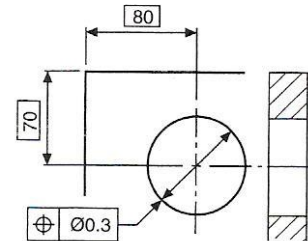
## Case 2

### Product requirement

The axis of the hole must be contained in a cylindrical tolerance zone of 0.3 diameter with its axis coincident with the theoretically exact position of the hole axis.



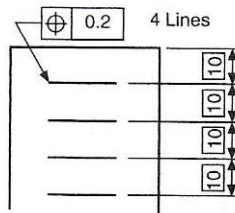
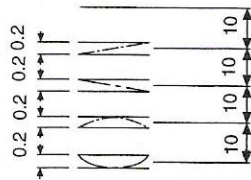
### Drawing instruction



## Case 3

### Product requirement

Each line must be contained between two parallel straight lines on the surface, 0.2 apart, which are symmetrical with the theoretically exact positions of the required lines.

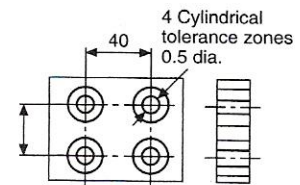


### Drawing instruction

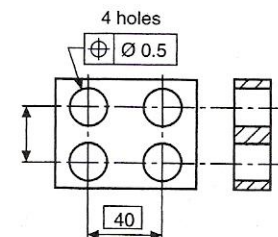
## Case 4

### Product requirement

The axes of each of the four holes must be contained in a cylindrical tolerance zone of 0.5 diameter, with its own axis coincident with the theoretically exact position of each hole.



### Drawing instruction

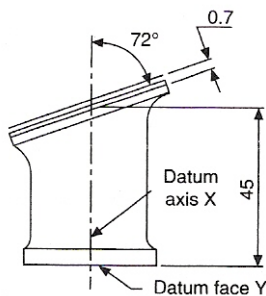
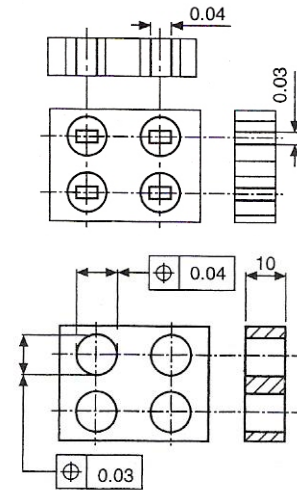


### Case 5

#### Product requirement

The axes of each of the four holes must be contained in a boxed zone of  $0.04 \times 0.03 \times 10$ , symmetrically disposed about the theoretically exact position of each hole axis.

#### Drawing instruction

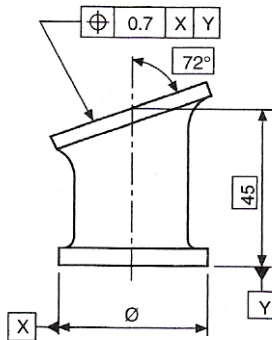


### Case 6

#### Product requirement

The angled surface must be contained between two parallel planes 0.7 apart, which are symmetrically disposed about the theoretically exact position of the surface relative to datum axis X and datum face Y.

#### Drawing instruction

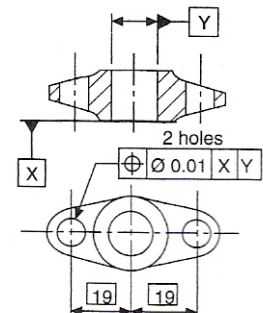
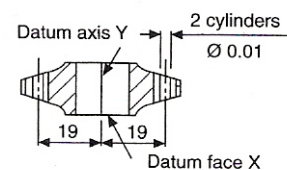


### Case 7

#### Product requirement

The axes of the two holes must be contained in cylindrical tolerance zones of 0.01 diameter, with their own axes coincident with the theoretically exact hole positions related to datum face X and the datum centre-line axis Y.

#### Drawing instruction





The characteristics to which it can be applied are as follows:

- straightness
- parallelism
- squareness
- angularity
- position
- concentricity
- 
- symmetry

The characteristics to which the maximum material condition concept cannot be applied are as follows:

- flatness
- roundness
- cylindricity
- profile of a line
- profile of a surface
- run-out

## Maximum Material Condition Applied to Straightness

Figure 1 shows a typical drawing instruction where limits of size are applied to a pin, and in addition a straightness tolerance of 0.2 is applicable at the maximum material condition.

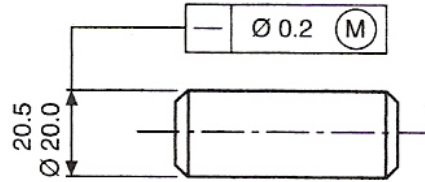


Figure 1

Figure 2 shows the condition where the pin is finished at the maximum material condition with the maximum straightness error. The effective assembly diameter will be equal to the sum of the upper limit of size and the straightness tolerance.

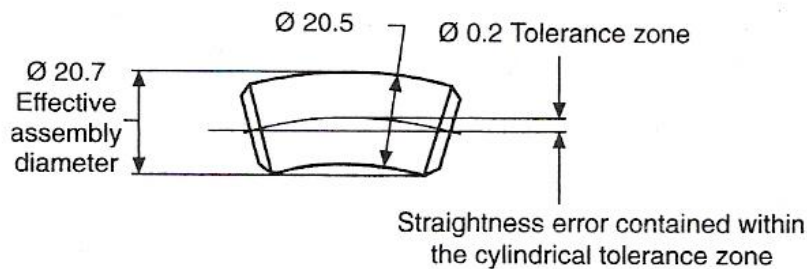


Figure 2

The straightness error is contained within a cylindrical tolerance zone of  $\varnothing 0.2$ .

To provide the same assembly diameter of 20.7 as shown in Figure 3 when the pin is finished at its low limit of size of 20.0, it follows that a straightness error of 0.7 could be acceptable. This increase may in some cases have no serious effect on the function of the component, and can be permitted.

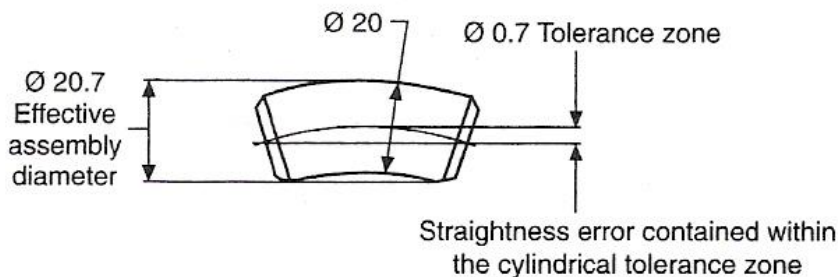


Figure 3

## Maximum Material Condition Applied to Squareness

Figure 4 shows a typical drawing instruction where limits of size are applied to a pin, and in addition a squareness tolerance of 0.3 is applicable at the maximum material condition.

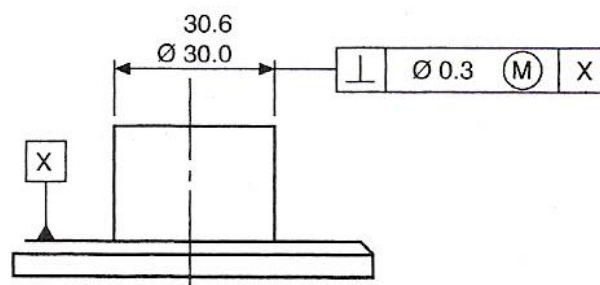


Figure 4

Figure 5 shows the condition where the pin is finished at the maximum material condition with the maximum squareness error of 0.3. The effective assembly diameter will be the sum of the upper limit of size and the squareness error. The squareness error will be contained within a cylindrical tolerance zone of  $\varnothing 0.3$ .

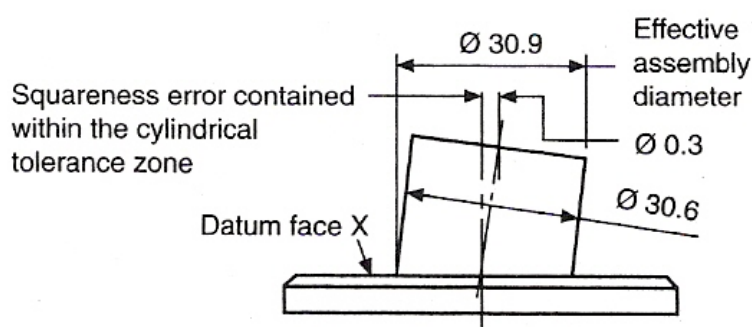


Figure 5

To provide the same assembly diameter of 30.9, as shown in Figure 6, when the pin is finished at its low limit of size of 30.0, it follows that the squareness error could increase from 0.3 to 0.9. This permitted increase should be checked for acceptability.

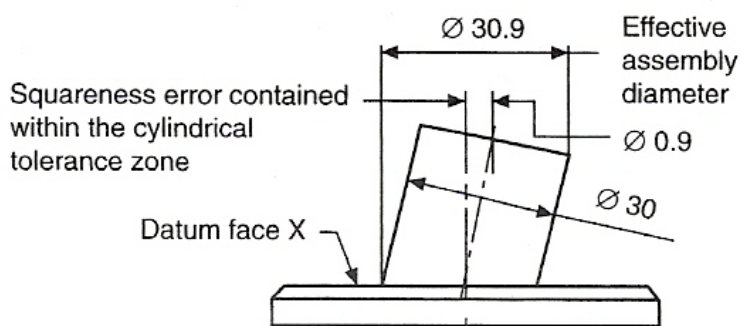


Figure 6

## Maximum Material Condition Applied to Position

A typical drawing instruction is given in Figure 7, and the following illustrations show the various extreme dimensions which can possibly arise.

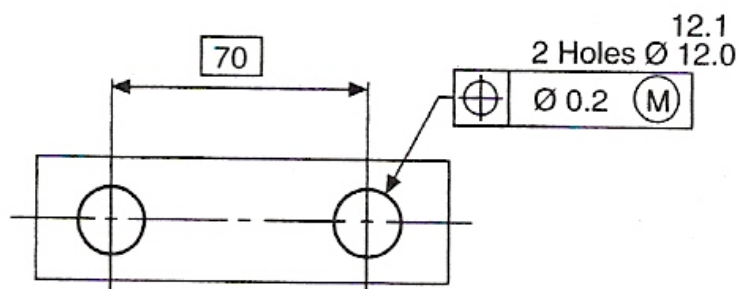


Figure 7

### Condition A (Figure 8)

Minimum distance between hole centres and the maximum material condition of holes.

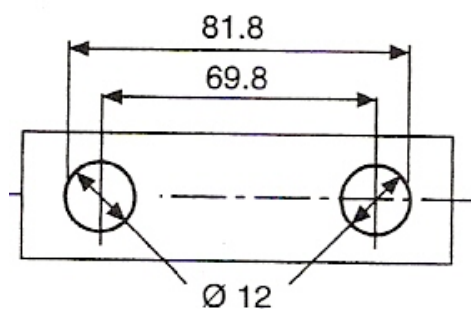


Figure 8

### Condition B (Figure 9)

Maximum distance between hole centres and maximum material condition of holes

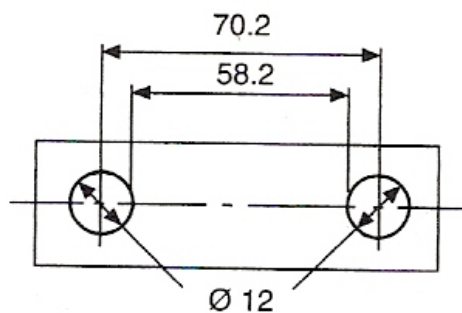


Figure 9

Condition C (Figure 10).

To give the same assembly condition as in A, the minimum distance between hole centres is reduced when the holes are finished away from the maximum material condition.

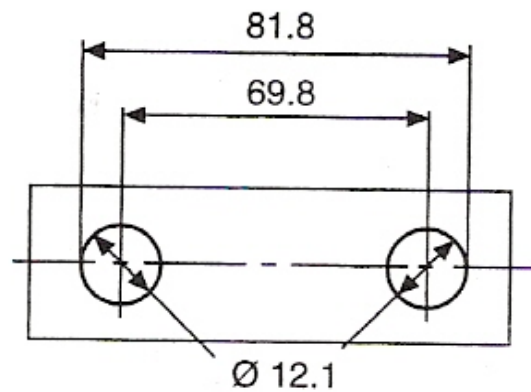


Figure 10

Condition D (Figure 11)

To give the same assembly condition as in B, the maximum distance between hole centres is increased when the holes are finished away from the maximum material condition.

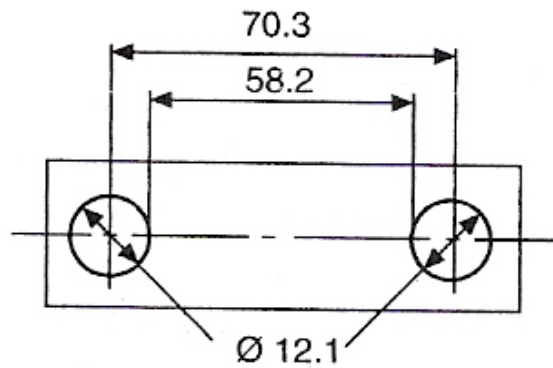


Figure 11

Note that the total tolerance zone is  $0.2 + 0.1 = 0.3$ , and therefore the positional tolerance can be increased where the two holes have a finished size away from the maximum material condition.

## Examining Stress/Strain Testing on Structural Steels

### Non-Destructive Testing

One of the biggest breakthroughs in this area has been the progress made in non-destructive testing (NDT). Powerful X-ray equipment or the use of radioactive isotopes enable us to look right inside and examine the results on a film in much the same way as a surgeon would examine a medical X-ray (Figure 12).

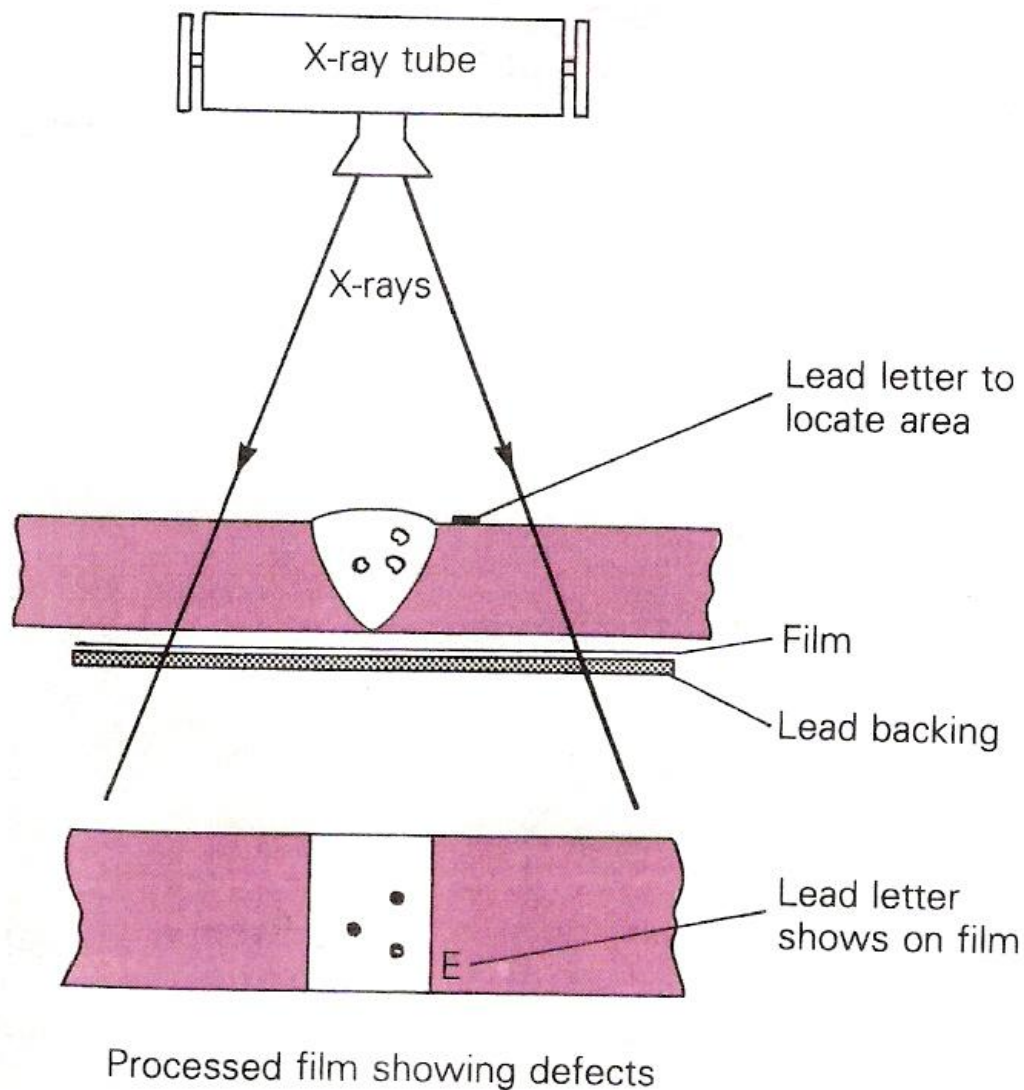
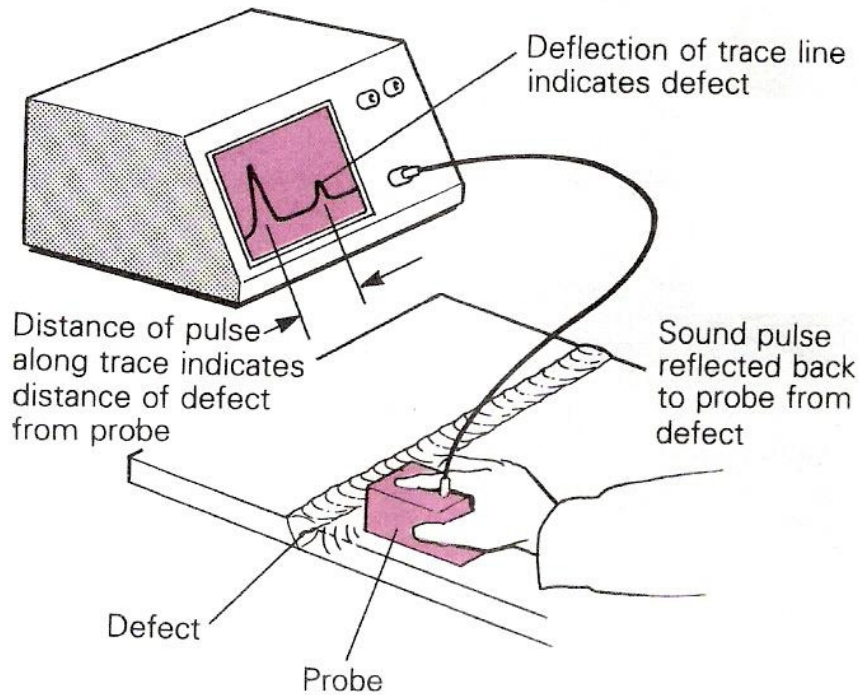


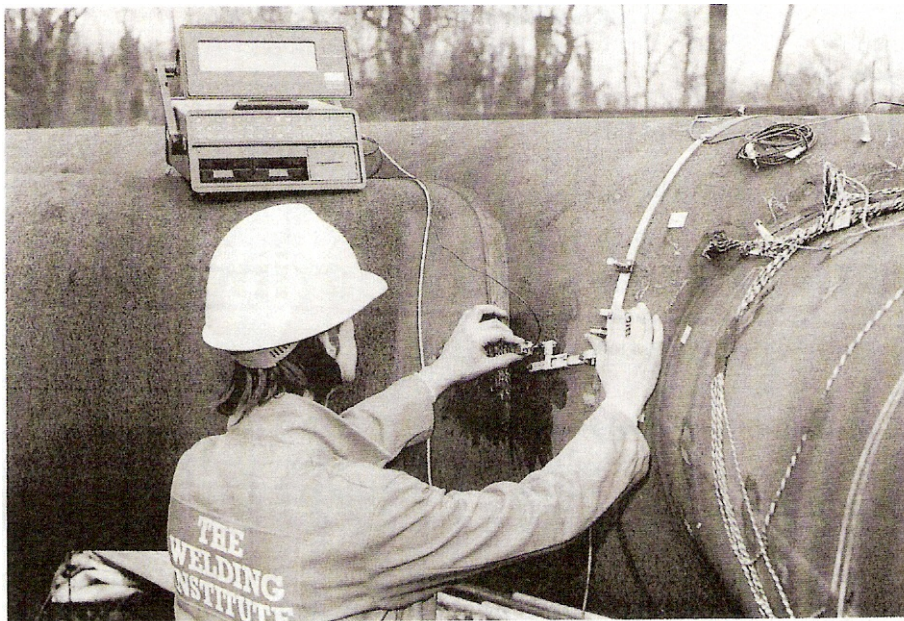
Figure 12 - X-Ray Inspection



Ultrasound (pulses of high-frequency sound) can also be used (Figure 13). When the equipment is used by a skilled operator it can produce information about the quality of a structure without the stringent safety precautions required for the use of X-rays and radioactive isotopes (Figure 14).



**Figure 13 - Ultrasonic Inspection**

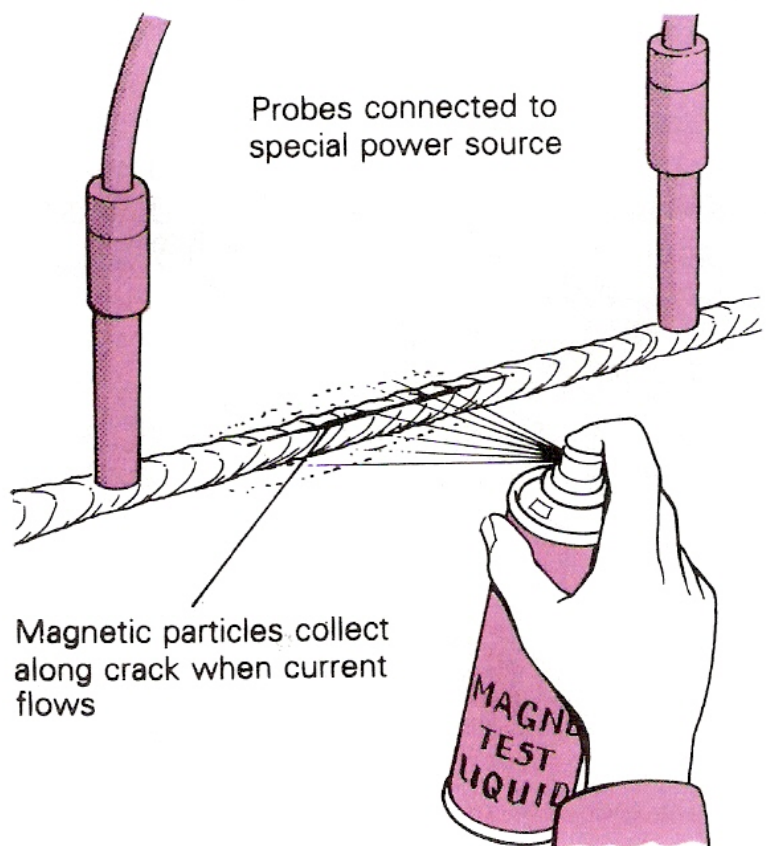


**Figure 14 - On-Site Inspection of Node Joint using Ultrasonic Equipment**

Miniature television cameras are often used to inspect the penetration of welds in small-diameter pipes.

Special dyes are employed in the dye penetrant test. These dyes will find their way into any surface defects and highlight them on subsequent inspection as, after the work has been wiped, the dye will remain in the defect. Some dyes are fluorescent in ultraviolet light.

Magnetic particle inspection works in a similar way, when oil containing iron powder is spread over the area and the work magnetised. The particles will gather around any surface or near surface defect (Figure 15).



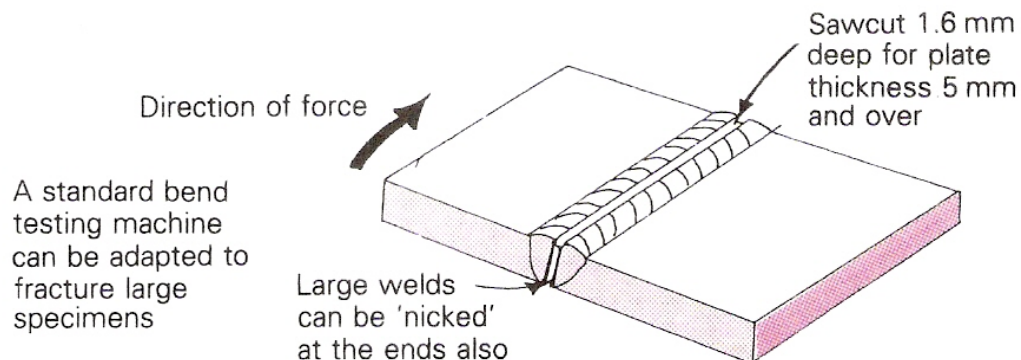
**Figure 15 - Magnetic Particle Inspection**

Use in a well ventilated area; never spray on a hot surface.



## Destructive Testing

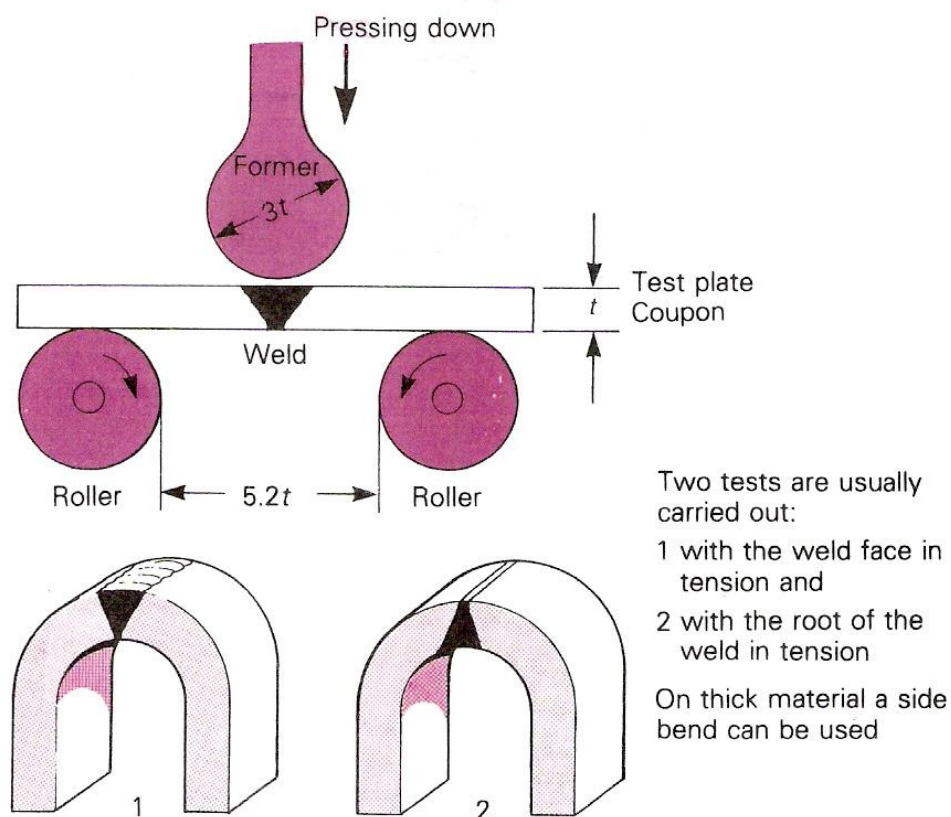
Many of these tests (such as the bend test and tensile test) will fail if there are internal defects present. Other tests, such as the nick break test, break open the weld so that we can see inside it. The macro-etch test will show fusion faces and internal defects.



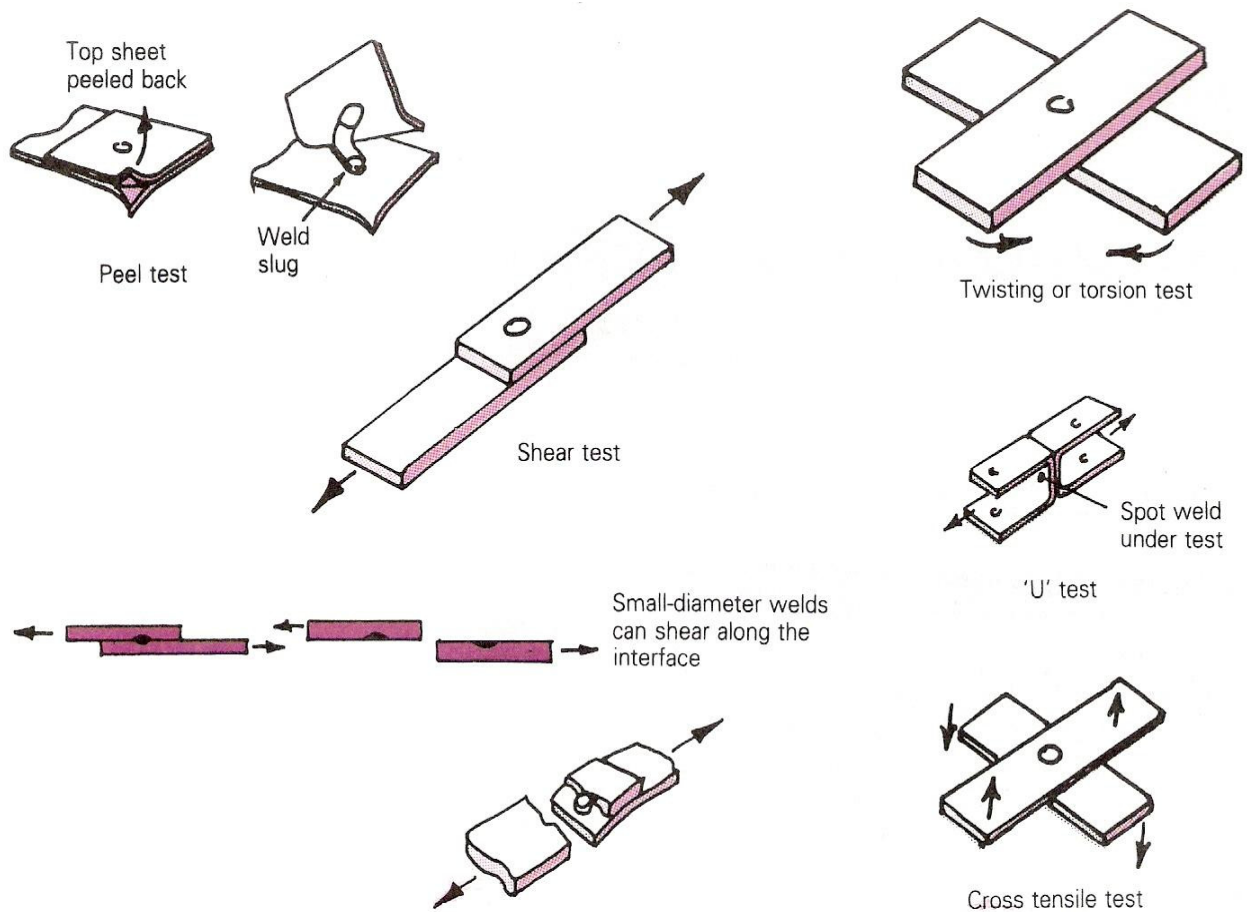
**Figure 16 - Butt Weld Specimen Prepared for a Nick Break Test**

## The Bend Test

If there is a fault in the structure, the bend test will probably reveal it by failure of the specimen.



**Figure 17 - Principle of the Bend Test**



**Figure 18 - Destructive Tests used to check Spot Welding Procedure**

- Other non-destructive methods such as magnetic particle and dye penetrant can be employed to check for surface defects that are difficult or impossible to see with the naked eye, such as very fine surface cracks and even cracks just below the surface in the case of magnetic particle inspection.
- Non-destructive tests allow the completed work to be examined without damaging it. Destructive tests, such as bend, tensile, macro etch and nick break, are often employed during welder training. They complement the non-destructive methods when examining a structural steel section.
- When a test piece is successful in passing the required testing procedures, a certificate is issued for insurance purposes. This certificate lists the date of the test.

## **Properties and Structure of Metals**

### **Introduction**

Having looked at the structure of materials in general, we now need to look more closely at the structure of metals, and at what happens when metals are welded. This will help you to appreciate the care that is needed when you are performing welding operations, and why you have to use different techniques and procedures with different metals.

However, first we need to look at the overall properties of metals, so that we can understand how these properties are affected by the details of the structure.

### **Properties of Metals**

Different metals have different mechanical properties. These properties determine how metals behave in use. The mechanical properties of interest to the engineer are described below.

#### **Ductility**

A ductile metal is one that can be easily drawn into a rod or a wire (Figure 19). A metal's ductility is determined by the amount it will stretch, lengthwise, before it becomes brittle and fails.

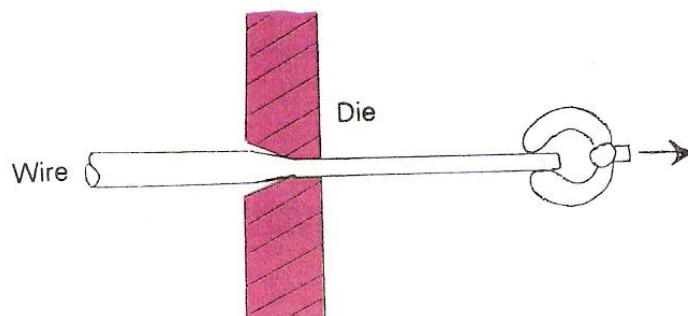
For a metal to be ductile, the molecules must have a great attraction for each other after the yield point has been passed. As the molecules have a greater attraction for each other when cold, metals will be more ductile when cold. This is why wires and rods for the welding industry are drawn in the cold state.

#### **Plasticity**

This measures a metal's ability to be formed into a specified shape without fracturing, and to remain in that shape once the load has been removed. Plasticity usually increases with rise in temperature. Very few metals are plastic in the cold state, so heat is normally used when forming, to increase plasticity. For example, iron and steel are difficult to bend when cold, but bend easily when red hot. There are odd exceptions to this, when an increase in temperature can cause brittleness (see below) in some metals. Wrought iron, for example, is plastic, but can sometimes break (because of impurities) when red-hot.

### Brittleness

This is the opposite of plasticity. It refers to a metal's tendency to break suddenly when under load, without any appreciable deformation. Many metals in their cast state will fracture when subjected to a large enough impact. In some metals, an increase in temperature can reduce brittleness, while in others it can increase it. For example, copper is a ductile metal, but it becomes brittle near its melting point. In general, most metals become less brittle when you apply heat to them. You should take special care when welding brittle metals, because of their lack of ductility.



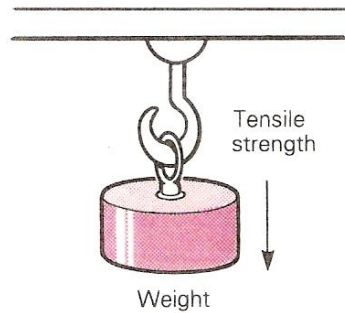
**Figure 19 - Wire needs to be ductile in order to be drawn through a die**

### Malleability

This property allows a metal to be compressed without failure. The metal can therefore be permanently flattened or stretched by hammering or rolling. The more malleable a metal is, the thinner the sheets into which it can be formed. Metals, such as iron and steel, become much more malleable with increased temperature. Copper is very malleable except near its melting point. Zinc is only malleable between 140°C and 160°C. Any impurities will reduce malleability. A rivet needs to be made of a malleable material in order to withstand the hammering.

Here is a list of some metals in order of decreasing malleability:

- Gold      Au
- Silver     Ag
- Aluminium Al
- Copper    Cu
- Tin        Sn
- Lead      Pb
- Zinc       Zn
- Iron       Fe



**Figure 20 - Tensile Strength**

### **Hardness**

This is usually defined as a metal's ability to resist indentation or abrasion. The measurement of hardness is usually based on a metal's resistance to the indentation of either a hardened steel ball (the **Brinell hardness test**) or a diamond (the **Vickers** or **Rockwell hardness tests**). Abrasion tests are sometimes used, as in the shot- and sand-blasting industries, for example.

Hardness can be increased by deformation caused by cold working. This is known as **work hardening**. In steels, carbon is the main hardening element, and in many ferrous alloys high levels of hardness can be obtained by heating the alloy to a high temperature followed by rapid cooling.

### **Tensile Strength**

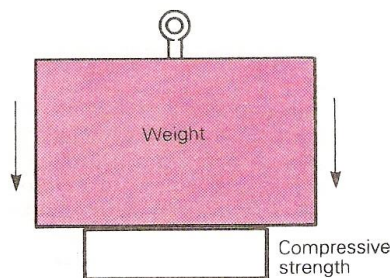
This measures a metal's ability to withstand a stretching load without breaking (Figure 20). Another name for tensile strength is **tenacity**.

### **Toughness**

This is a combination of ductility and tenacity. It is the property that enables a material to resist fracture by bending, twisting or shock.

### **Compressive Strength**

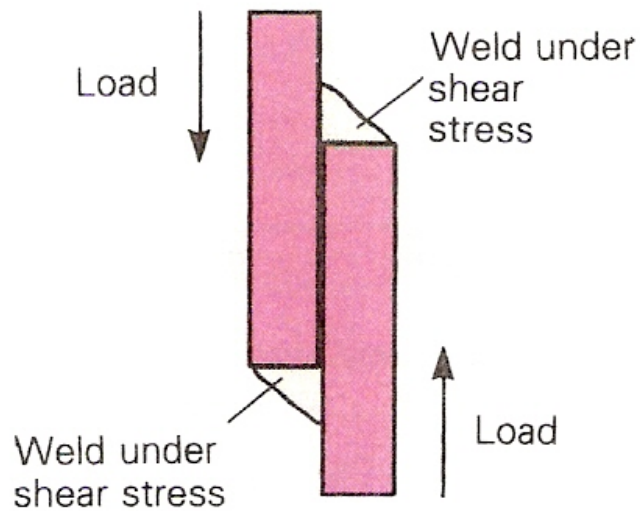
This is the property that enables a metal to withstand compressive loading without fracture (Figure 21).



**Figure 21 - Compressive Strength**

### Shear Strength

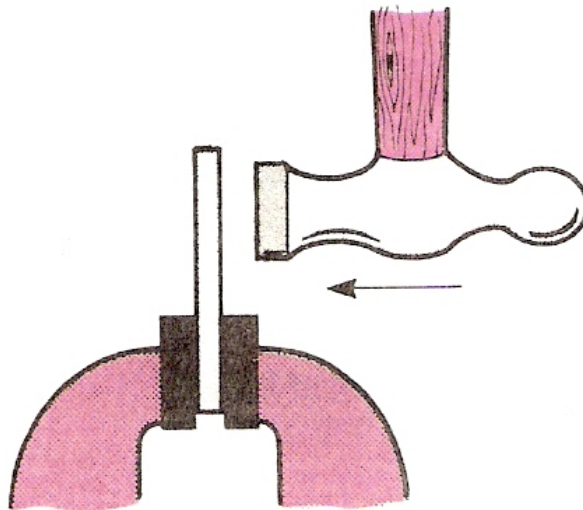
This measures a metal's ability to withstand loads that are not in the same line of force (offset loads) (Figure 22).



**Figure 22 - Shear Strength**

### Impact Strength

This measures a metal's ability to withstand impact (Figure 23).



**Figure 23 - Impact Strength**

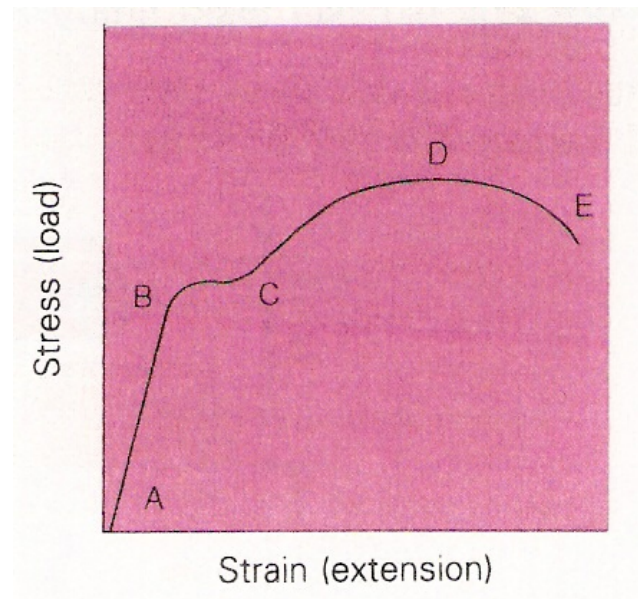
### Elasticity

This measures a metal's ability to deform under load and then return to its original shape once the load has been removed. A spring is a good example of elasticity.

## Stress-Strain and Tensile Strength

A tensile testing machine is specially designed to pull specimens of specified dimensions to breaking point in order to determine some of the metal's properties.

When the specimen is under tensile stress and the load is gradually increased until breaking point occurs, then the specimen will pass through certain phases. These phases can be shown by plotting a **stress-strain curve**. The curve is found by taking a number of load (Figure 24) shows a typical stress-strain curve for a ductile material such as low-carbon steel. From A to B, the straight line indicates that the extension is proportional to the load. Between these points, the material still retains its elasticity, so that if the load is removed the specimen will return to its original length.



**Figure 24 - Stress-Strain Curve for a Ductile Material**

If the extension (strain) is proportional to the applied load (stress), the metal is said to have obeyed **Hooke's law**.

For example, if the stress increases by 50 per cent, the strain will also increase by 50 per cent, producing a straight line, which will indicate the elastic range of the material.

$$\text{Stress} = \frac{\text{Load}}{\text{cross-sectional area}}$$

$$\text{Strain} = \frac{\text{Extension of gauge length}}{\text{Original gauge length}}$$

$$\text{Hooke's law} = \frac{\text{Stress}}{\text{Strain}} = E$$

where E is a constant known as **Young's modulus**.

From B to C, the metal extends with no increase in load. The specimen is said to have taken **permanent set**; if the load is removed at this stage, the metal will not return to its original length. This is known as the **yield point**.



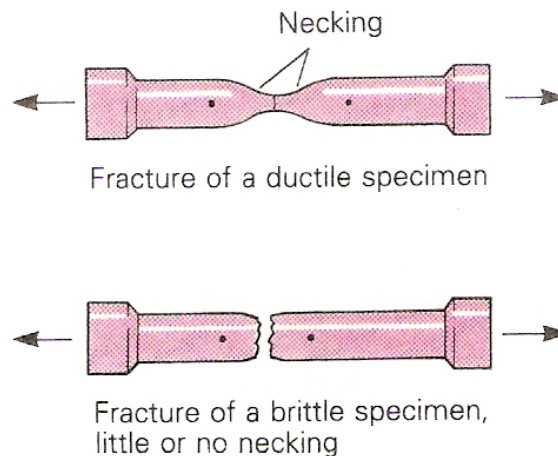
From C to D the extension is no longer proportional to the load. If the load is removed, little or no spring-back will occur. In this stage the metal is said to be plastic.

Point D is the ultimate tensile stress of the material and point E represents the breaking point (or fracture point). From D to E the material appears to continue stretching under reduced load. In fact, the specimen, because it is a ductile material, is thinning out (necking), until it finally breaks at point E.

To calculate the ultimate tensile strength (UTS) of the metal, the maximum load indicated on the stress-strain curve (D) is divided by the original cross-sectional area. The UTS is mainly of use at the design stage.

The yield stress is calculated by taking the load at point B and dividing by the original cross-sectional area of the specimen. It is usual for designers to work at 50 per cent of this figure to give a 'safety factor'.

The elongation percentage is found by taking the increased length at fracture and dividing it by the original length. The resulting figure is expressed as a percentage and is an accurate indication of the material's ductility.

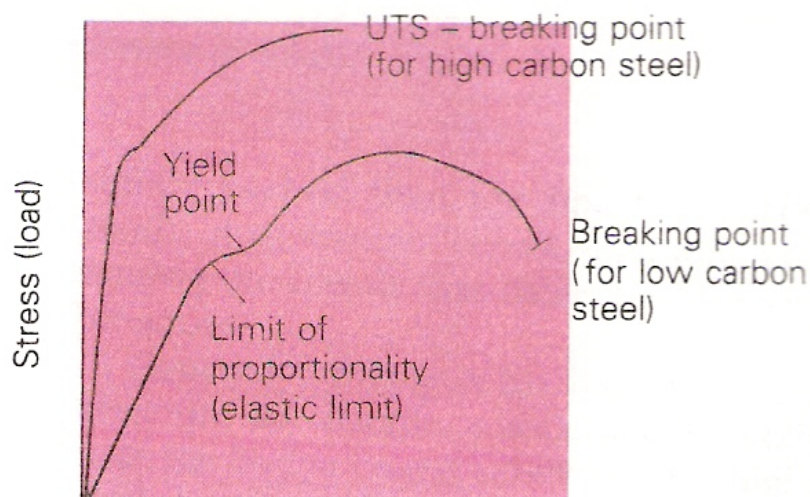


**Figure 25 - Comparing the Failure of a Ductile Specimen and a Brittle Specimen after Loading**

A brittle material will show little or no 'necking' and will fracture in a brittle manner, usually with a bang (Figure 25). Figure 26 compares the stress-strain curve for a high-carbon steel with that of a low-carbon steel. It shows that the carbon steel:

1. has a longer line of proportionality (elasticity);
2. indicates a higher yield point load;
3. has a higher ultimate tensile strength.
4. shows less elongation;
5. has its UTS and breaking point together.



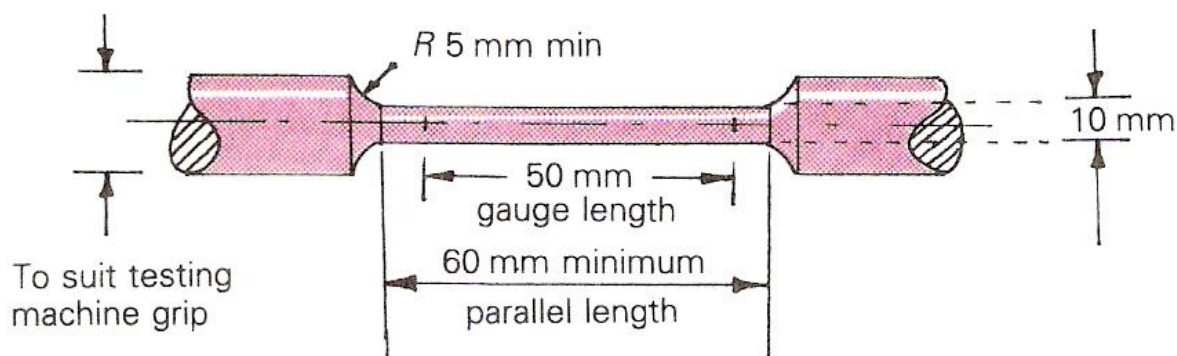


**Figure 26 - Comparing the Stress-Strain Curves of High-Carbon Steel and Low-Carbon Steel**

This comparison shows that an increase in hardness will normally produce an increased tensile strength, but a reduction in ductility.

For certain welding tests, specimens can be machined entirely from weld metal. Figure 27 shows an example of an all-weld-metal specimen. In this specimen:

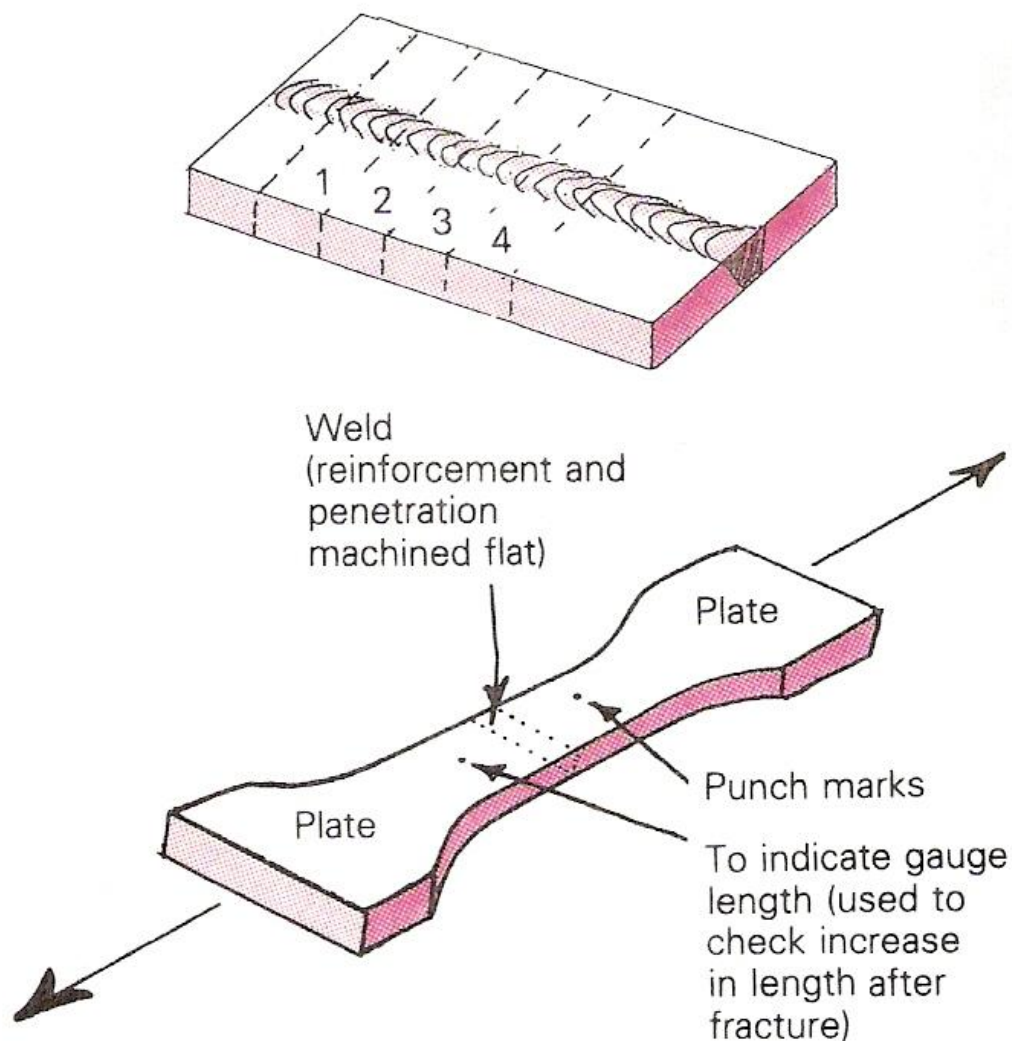
$$\begin{aligned}
 \text{Gauge length} &= 5.65 \sqrt{\text{cross-sectional area}} \\
 &= 5.65 \sqrt{78.55} \\
 &= 5.65 \times 8.862 \\
 &= 50
 \end{aligned}$$



**Figure 27 - An All-Weld-Metal Test Specimen**

Figure 28 shows an example of a tensile test specimen including plate material and weld. Depending on the code, sections 1 and 3 can be used for tensile specimens, and sections 2 and 4 can be used as bend test specimens.

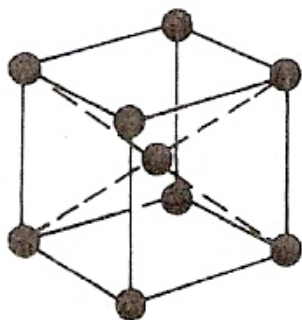
Always check exact dimensions of tensile specimens against the requirements of the welding code or standard that you are working to.



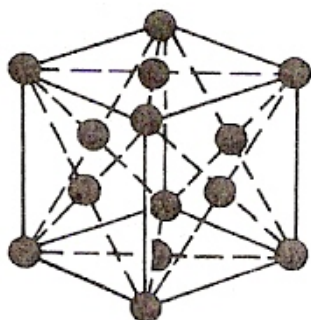
**Figure 28 - Tensile Test Specimen Including Plate Material and Weld**

## Structure of Metals

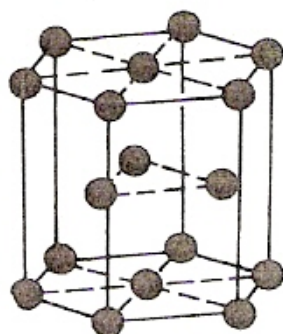
There are three main types of structure into which metallic elements (metals) crystallise. The three space lattice patterns in Figure 29 show graphical representations of the orderly geometric patterns into which the atoms arrange themselves on cooling from the liquid to the solid state.



Body-centred cubic



Face-centred cubic



Hexagonal close-packed

**Figure 29 - Three Main Types of Lattice Structure into which Metallic Materials Arrange Themselves**

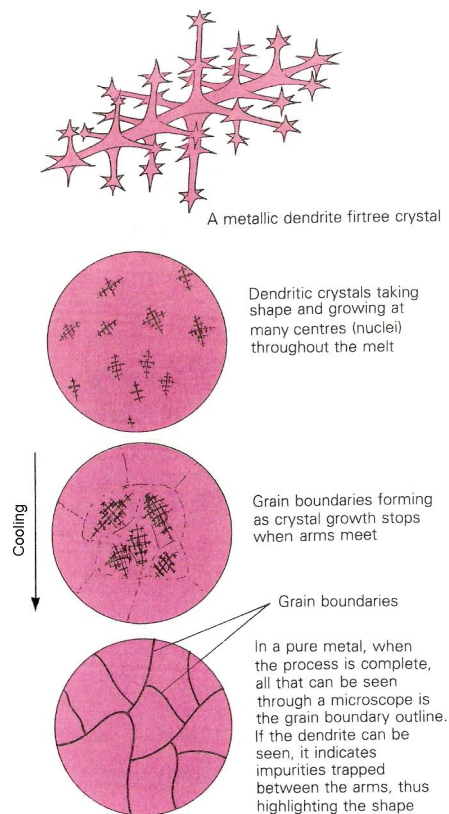
The body-centred cubic structure has nine atoms, one at each corner of the cube and one at the centre. This crystal pattern is found in such metals as iron, molybdenum, chromium, tungsten and vanadium.

The face-centred cubic structure, as its name implies, has an atom in the centre of each face. Typical metals with this space lattice pattern are aluminium, copper, nickel, lead, platinum, gold and silver.

The close-packed hexagonal structure is more tightly packed than the first two. Cadmium, bismuth, magnesium, cobalt, titanium and zinc are among the metals that have this type of crystalline structure.

Generally, metals with the face-centred lattice structure are ductile, plastic and workable. Metals with the body-centred structure have higher strength with lower cold-working properties. Metals with the close-packed hexagonal lattice lack plasticity and cannot be cold worked.

In a pure metal, these individual crystals will start to form at many centres (or nuclei) throughout the cooling material. The process starts with one unit of the crystal lattice and rapidly builds up with the addition of atoms and lattice structures into a crystal framework called a dendrite (Figure 30).



**Figure 30 - Stages of Crystallisation as a Metal Solidifies**  
(Viewed under a microscope)

From the dendrite, arms of space lattices start to grow in other directions, giving an appearance similar to a fir tree with the growth of its twigs and branches. The dendrite is sometimes called a fir tree crystal because of this.

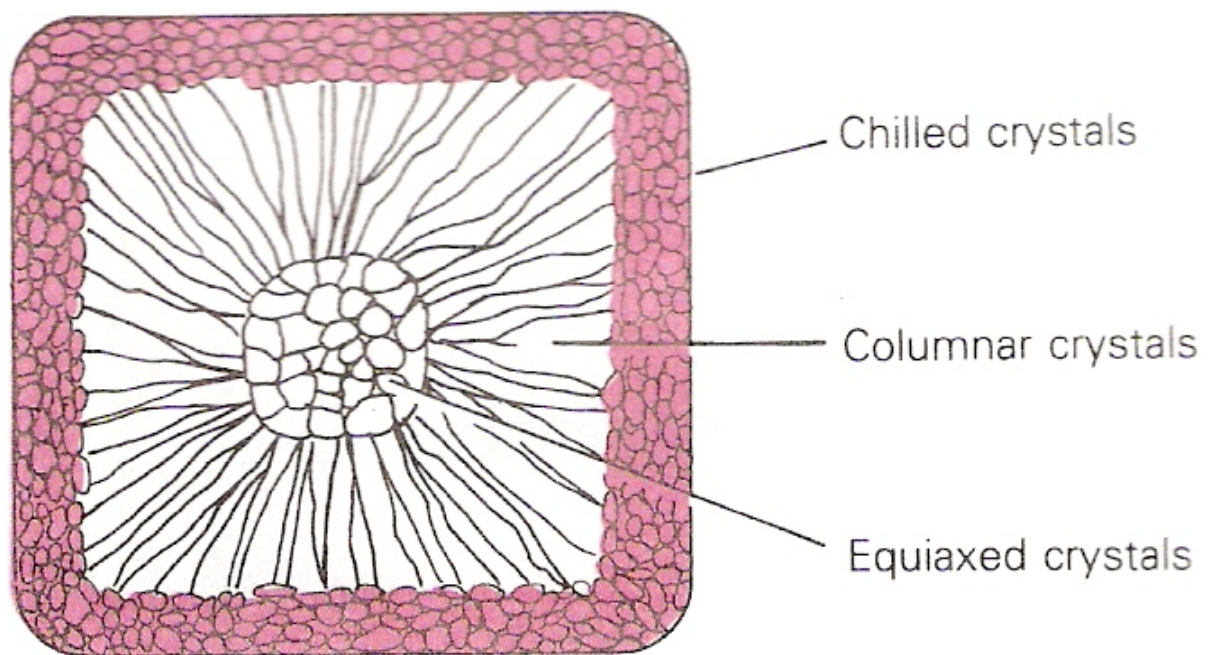
As the temperature continues to fall, the dendrite increases in size until its arms come into contact with other similar structures. At this point growth stops in that direction and solidification begins to take place between the arms of the dendrite. This solidification continues until the crystal is formed. Normally there is no trace of the original dendrite.

However, if impurities have been trapped between the dendrite arms, or if the metal has cooled too rapidly, metal may not have fed completely into the spaces between dendrites. This will cause shrinkage cavities and allow the outline of the dendrite to be visible.

### Effect of Rate of Cooling on Grain Growth

The rate at which a metal cools will affect the number of nuclei formed; slow cooling will promote the growth of fairly few nuclei. The result is that the crystals (or grains) will be large enough to be visible without the aid of a microscope. Fast cooling will promote many nuclei and a small fine-grain structure.

In a large ingot of cast metal or a large weld, the crystal sizes can vary considerably from the outer edges to the centre (Figure 31). This is due to variation in the temperature gradient, because as an ingot (or a large weld) solidifies, heat will be transferred from the metal to the mould (or the heavy parent material).



**Figure 31 - An Ingot of a Pure Metal Showing the Crystal Structure**

(Viewed under a microscope)

When the metal first makes contact with a cold mould there is a chilling effect and many small crystals form. As the mould warms up, the direction of cooling is mainly inwards and extremely elongated columnar crystals are formed. As heat is lost still further, the metal in the centre begins to form its own nuclei and a third type of crystal is formed, showing no preference for directional growth. These central crystals are much larger than the chilled crystals at the outer edges, because of their slower rate of cooling. These central crystals are known as equiaxed, because they have no preference for directional cooling.

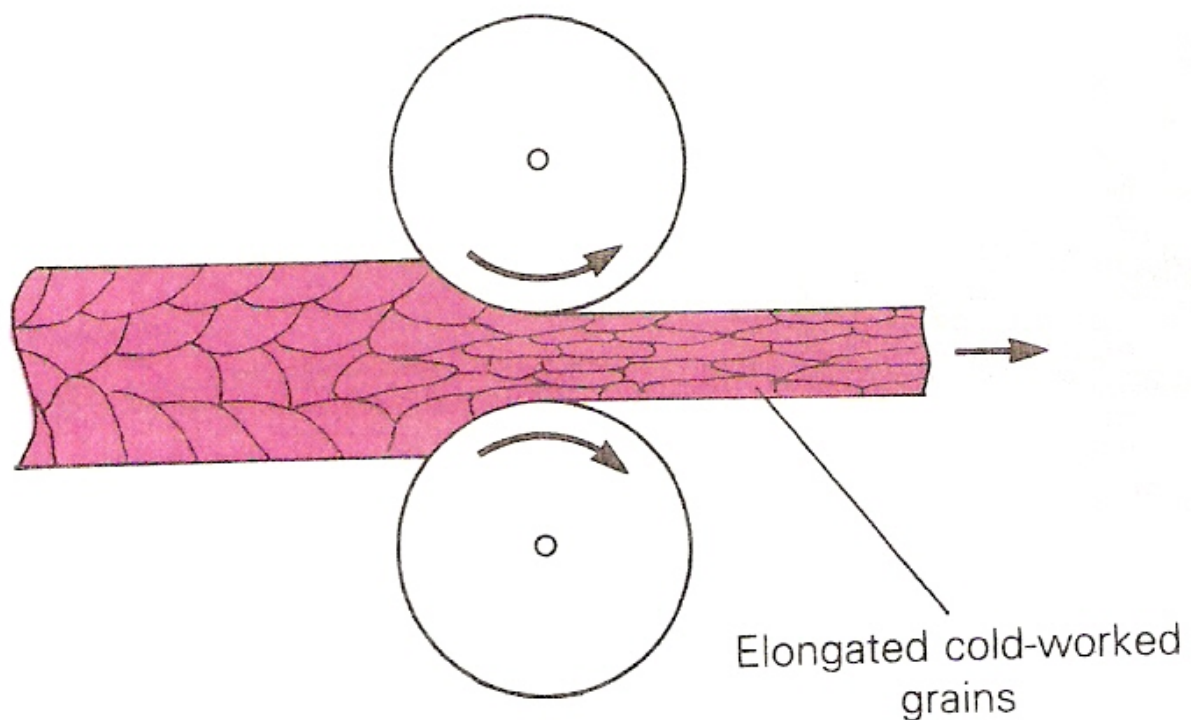


### Effect of Grain Structure on Metal Properties

The deformation of grains can have a big effect on the mechanical properties of a metal. Deformation can take place when a metal is being cold worked during operations such as hammering, pressing, rolling, drawing or bending. An example of how crystals can become greatly elongated and strain hardened is shown in Figure 32 where a plate is undergoing a cold-rolling operation.

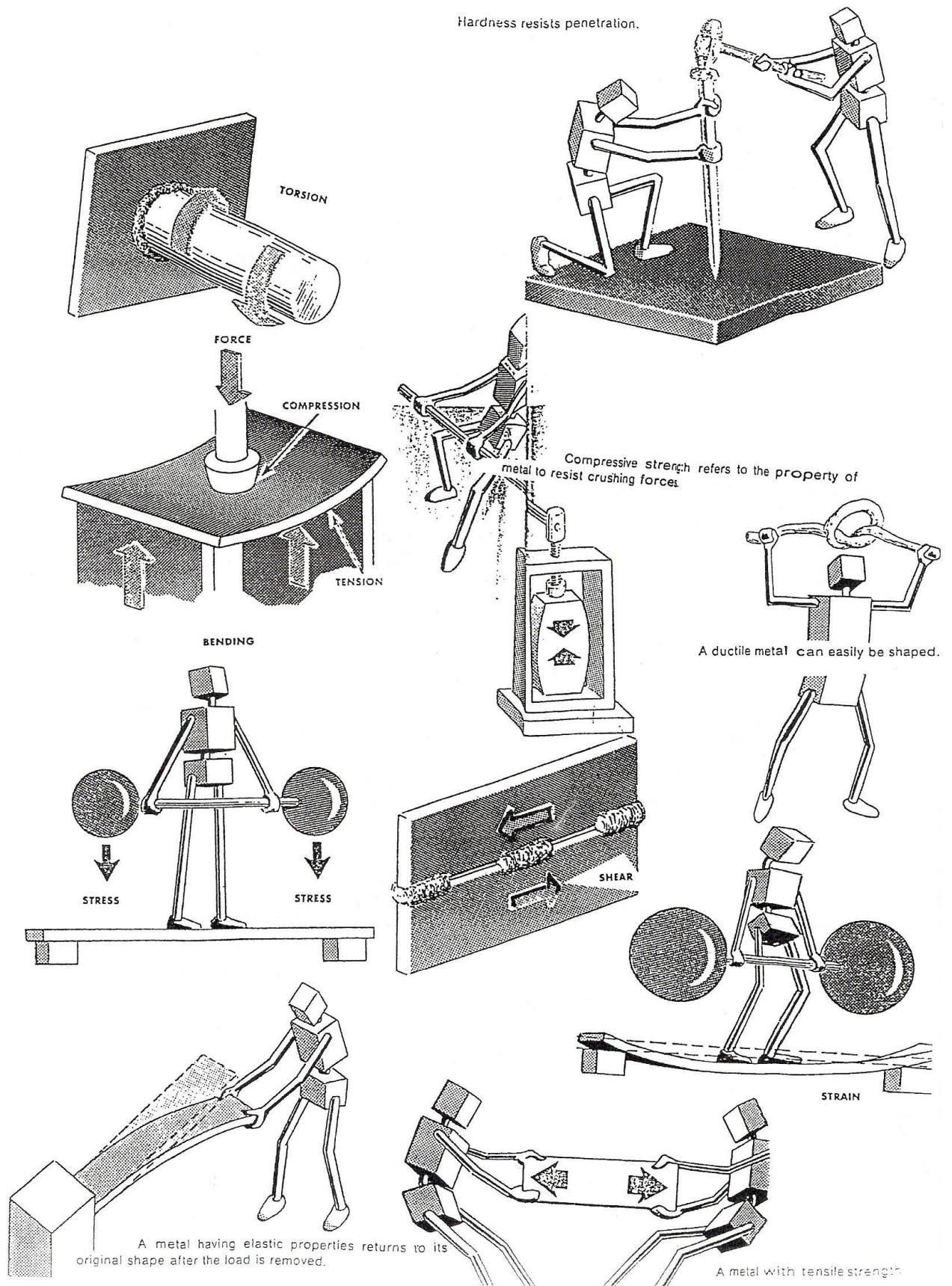
This undesirable structure can be rectified by applying enough heat to produce the growth of new equiaxed crystal grains, which will return the structure to an unstrained state with the same properties that it had before the cold working took place.

The temperature at which these new grains form is called the recrystallisation temperature. It is important to hold the metal at this temperature just long enough for the new grains to form, and then to control the cooling rate so that the structure will consist of the refined equiaxed crystals. If the metal is subjected to too much heating above its recrystallisation point, grain growth can occur. These weaker enlarged grains can also be formed if the cooling rate is too slow. Such enlarged grains can decrease ductility and tensile strength, but these properties could, of course, be restored by correct recrystallisation treatment.

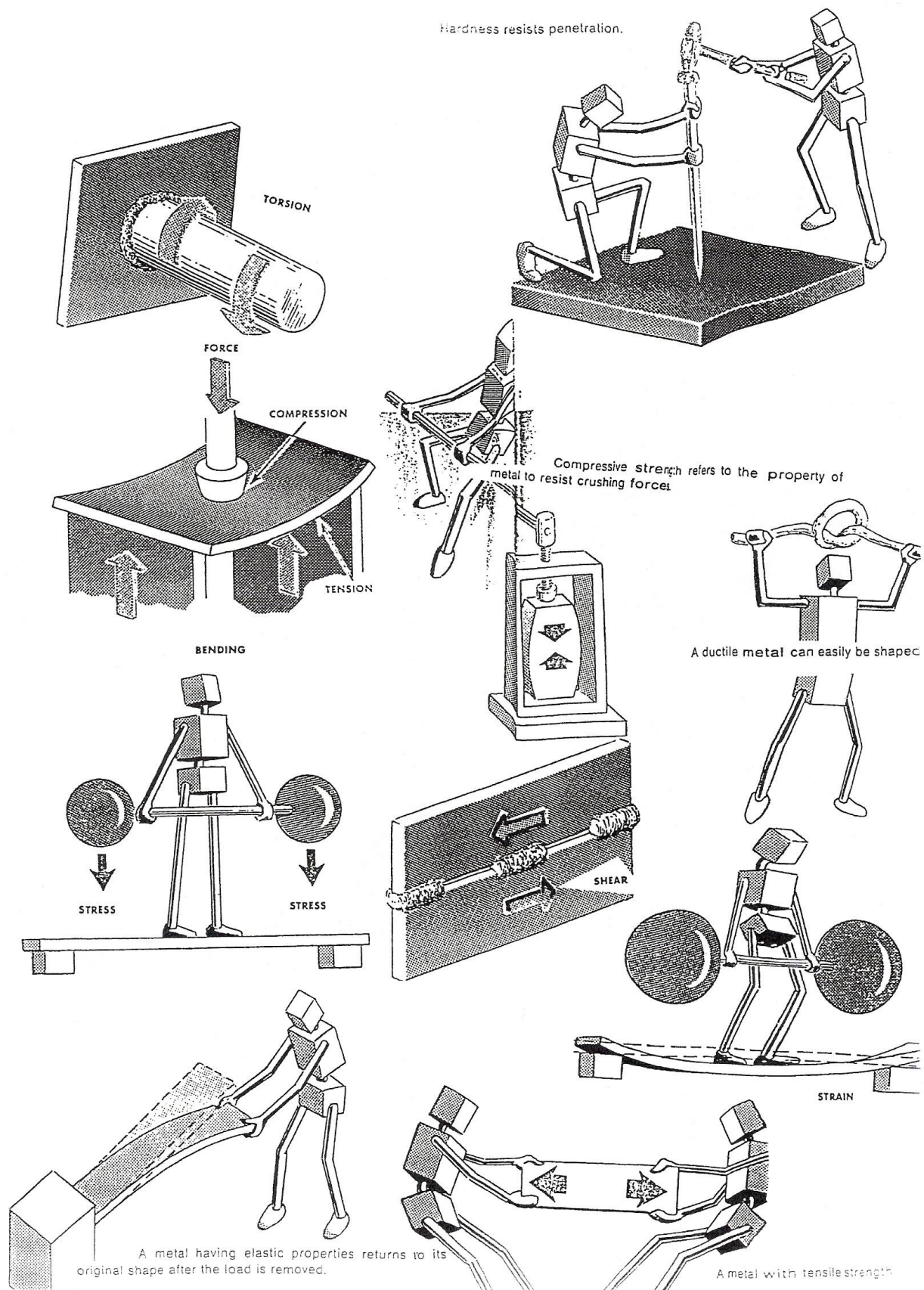


**Figure 32 - Cold Rolling of a Steel Plate**  
(Viewed under a microscope)

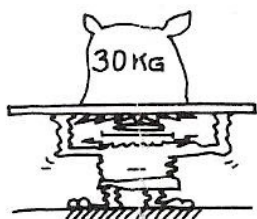
## Stresses on Metals



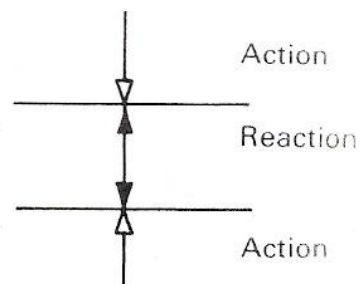




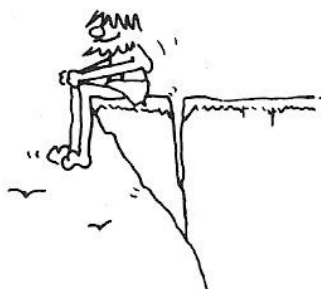
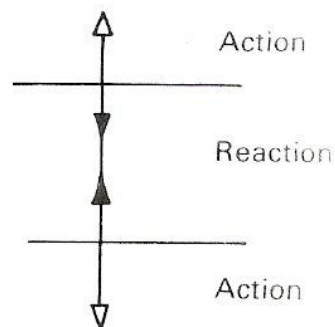




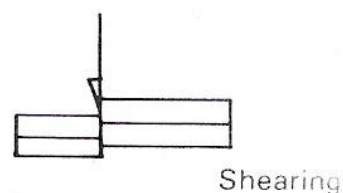
**Compression:** This is when something is squeezed and can result in crushing. If a member is under compression it is called a **strut**. This is arrowed as shown or sometimes is represented by a thick line.



**Tension:** This is when something is pulled and can result in stretching. If a member is under tension it is called a **tie**. It is arrowed as shown or sometimes is represented by a thin line.



**Shear:** This is when something is cut or slides and can result in sliding or shearing.



**Torsion:** This is when something is twisted and can result in warping.



**Note:** Many structural members are subject to a combination of forces, stresses and allowable strains.

**Figure 33 - Forces**

## Marking-Out, Measuring and Inspection Tools and Processes

Accuracy in metalwork is essential if the designed artefacts are to work satisfactorily. To produce good-quality workpieces, you therefore need to take great care in marking out, measuring and inspecting. Tools meant for these processes should form part of the equipment in the metal workshop of every institution.

### Marking-Out Tools

Before you can shape or form workpieces, you have to mark them to the required dimensions. The following tools are used in marking out.

You use the scribe, which has a hardened tool-steel tip, in conjunction with the try square to mark lines at right angles to or parallel to an angle. There are many patterns of scribe (Figure 34). The bent-end scribe can be used in awkward positions.

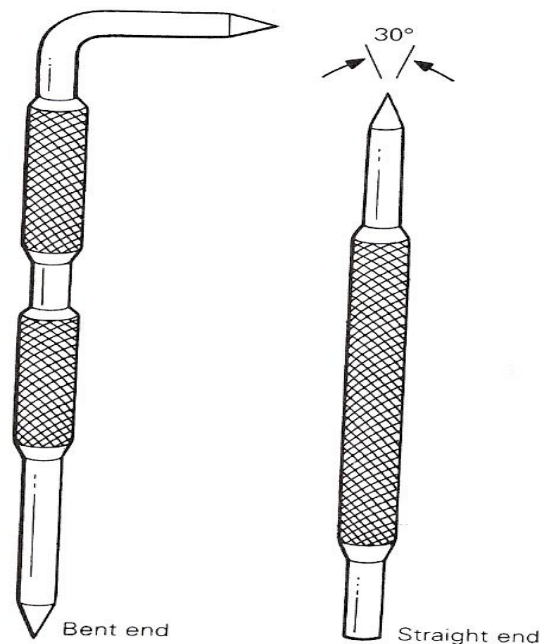


Figure 34 - Scribes

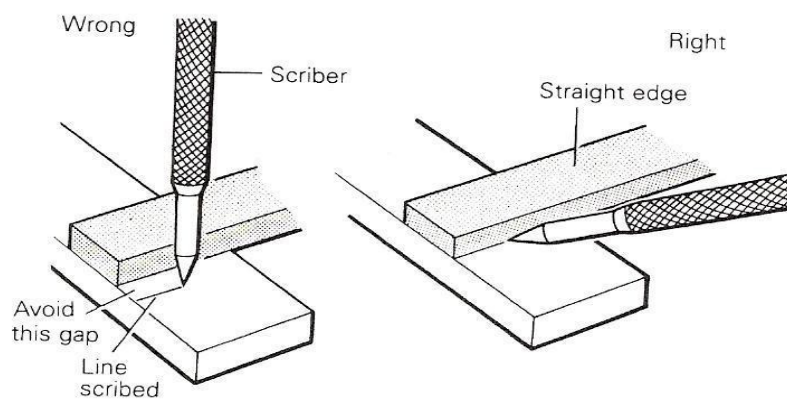
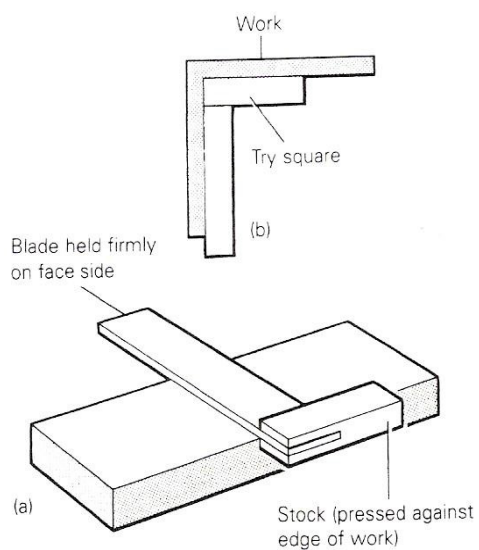
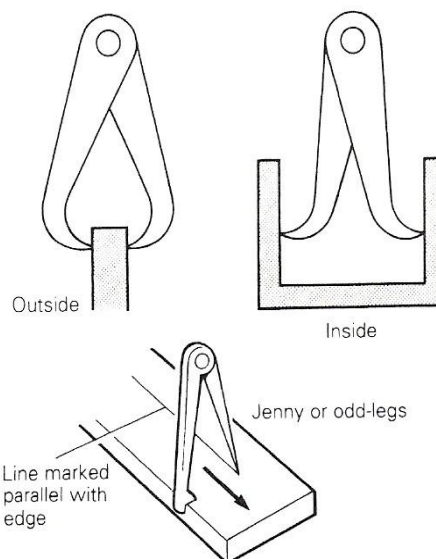


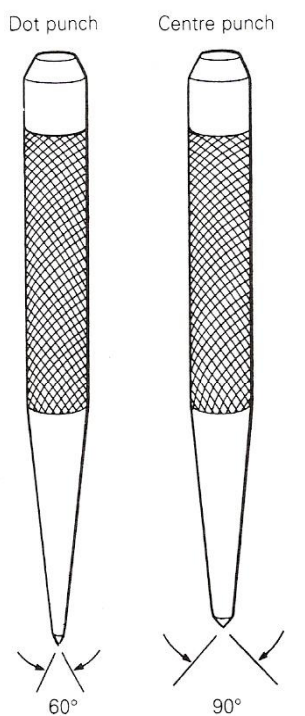
Figure 35 - Using the Scribe



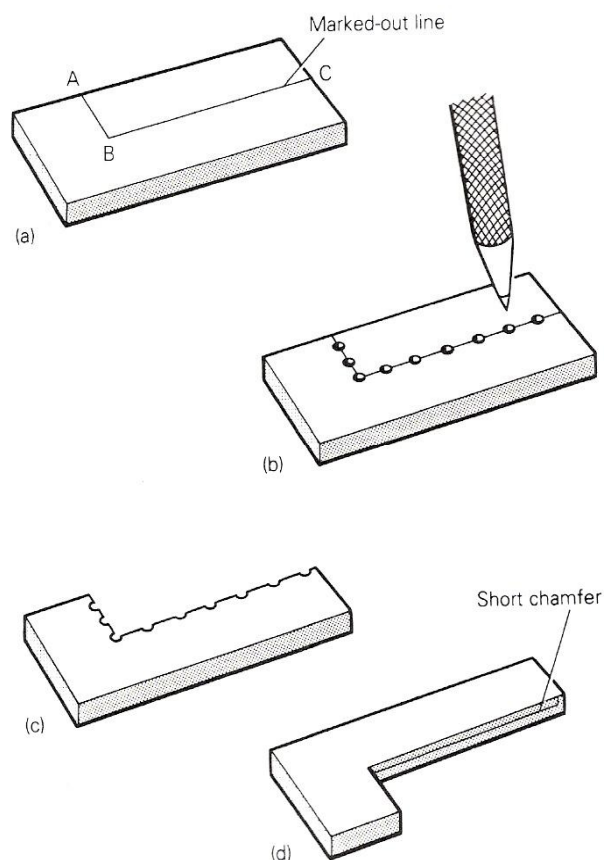
Using a try square: (a) marking out at right angles; (b) checking for squareness.



Using callipers.



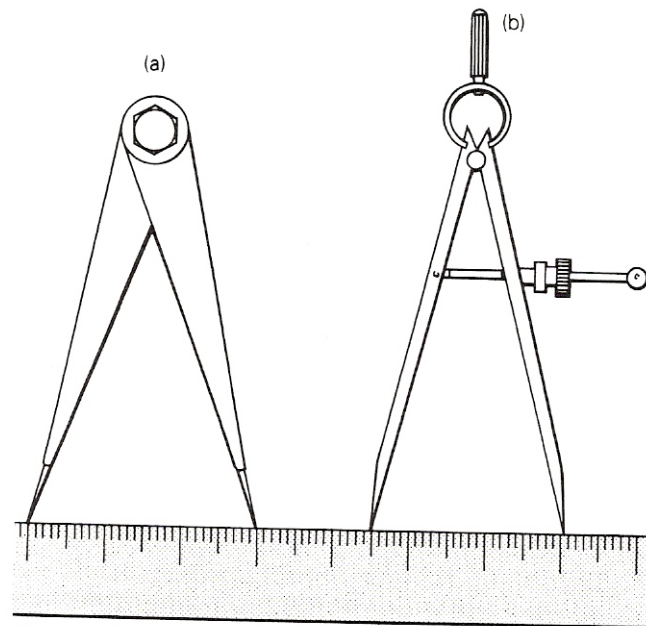
Dot and centre punches.



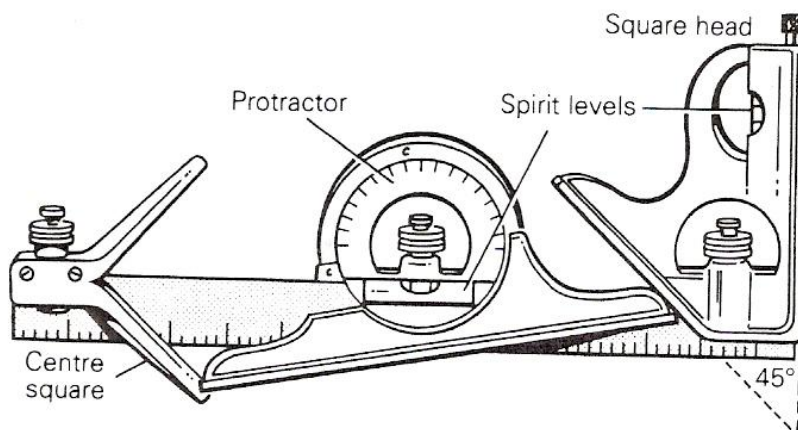
Stages in dot punching: (a) marking out; (b) dot punching; (c) filing or removing metal to line A-B-C; (d) chamfering to remove marks.

Figure 36

The combination set (Figure 38) is an important tool in the workshop, because you can use it as a centre square, a try square and a protractor for marking out, measuring and testing. There are three heads (protractor, square and centre), which slide onto a rule, which can be fixed at any position using the nut provided.



**Figure 37 - Setting Dividers: a) Firm-Jointed Type; b) Spring-Controlled Type**



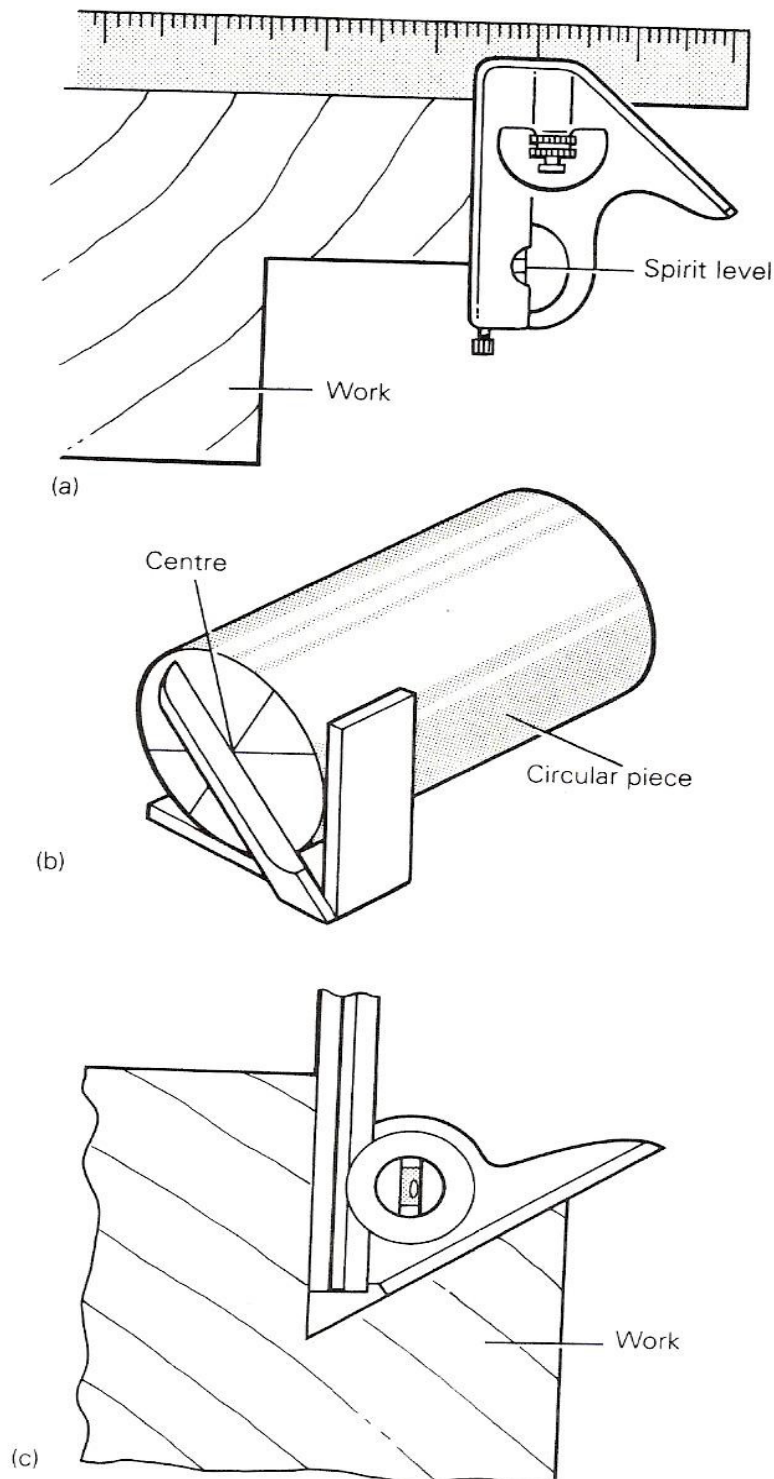
**Figure 38 - Combination Set**

The main parts of the combination set are used as follows.

1. The try square has angles of  $45^\circ$  and  $90^\circ$ , which you can use to mark out, or to check that a surface is vertical. You can also use it as a square (Figure 39(a)).
2. You can use the centre square to find the centre of circular pieces (Figure 39(b)).
3. You use the protractor with the rule to mark out or measure angular surfaces (Figure 39(c)).

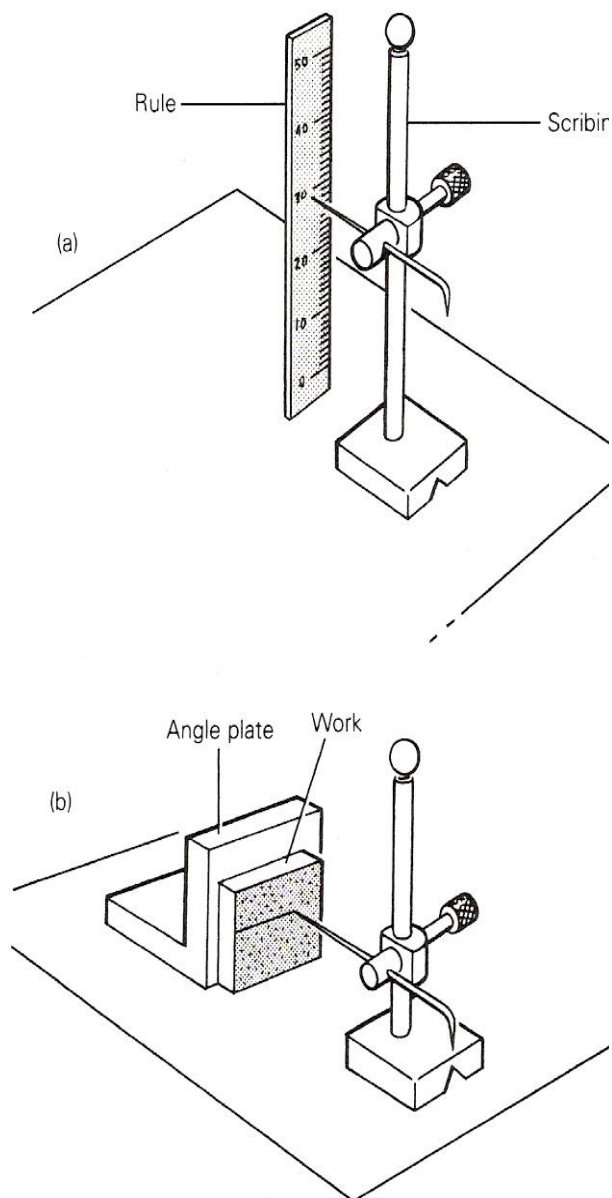
## Measuring and Inspection Tools

You can obtain detailed dimensions of workpieces using measuring tools such as the rule, or the combination set. You can also test existing features (such as holes) for accuracy using inspection tools such as plugs and gauges.



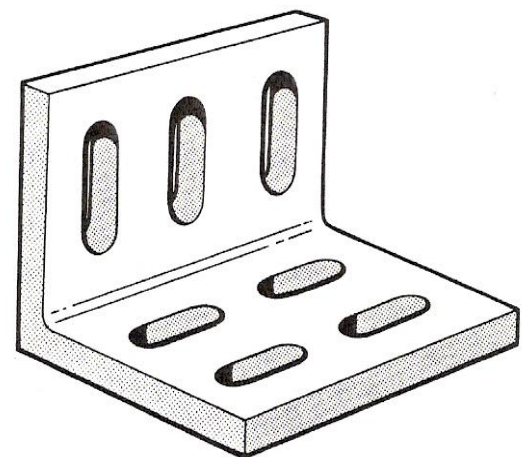
**Figure 39 - Using the Combination Set: a) Try Square; b) Centre Square; c) Protractor**



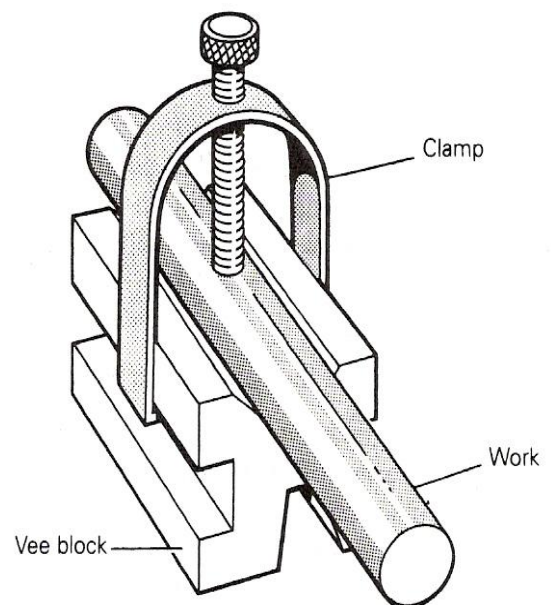


**Figure 40 - Using the Surface Gauge**

- a) Set the scriber.
- b) Hold the work against the angle plate and move the block against the work.



**Angle plate**



**Figure 41 - Using the Vee Block**

## High Strength Friction Grip Bolts (H.S.F.G.)

There are several types of H.S.F.G. bolt (Figure 42), but all must be tightened to the specified minimum tension.

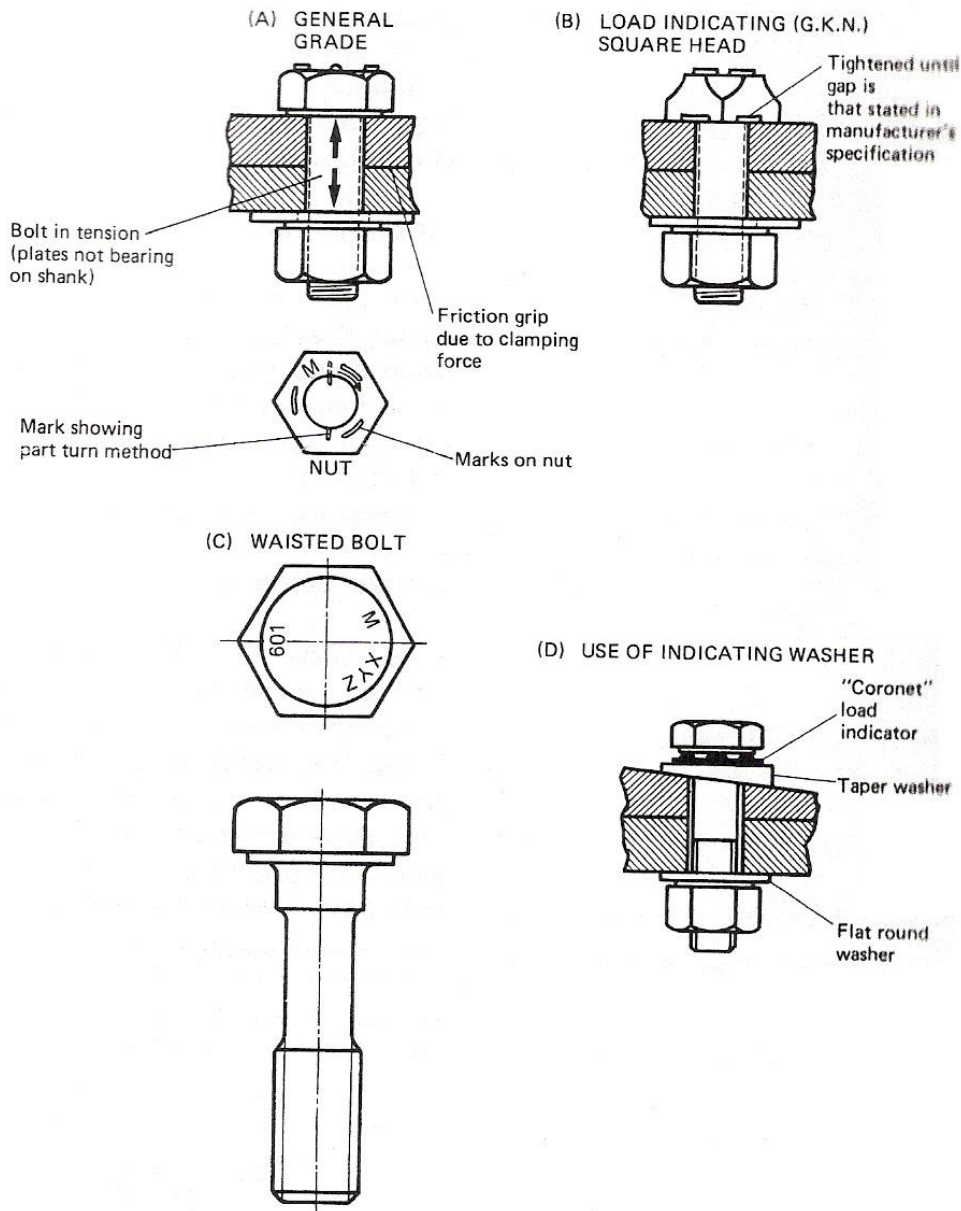
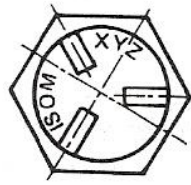


Figure 42 - High Strength Friction Grip Bolts

The term H.S.F.G. relates to bolts of high tensile steel, used in conjunction with high tensile steel nuts and hardened steel washers. They are tightened to a predetermined shank tension in order that the clamping force thus provided will transfer loads in the connecting members by friction between the parts and not by shear in, or bearing on, the bolts or plates of connecting members.

These bolts are made by a special cold working process which includes two operations: heading and thread rolling. Figure 43 shows the head for identification. Close tolerances ensure accuracy, and heat treatment is carried out afterwards.



**Figure 43 - Bolt Head**

ISOM = ISO metric identification; XYZ = manufacturer's (trade) marking; 601 = strength grade

The surfaces in contact must be free from paint, oil, dirt, loose rust and scale. Each bolt is assembled with one washer in cases where plane parallel surfaces are involved. The washer is placed under the bolt head or nut, whichever is to be rotated during the tightening operation. A tapered washer must be used also if the angle is above 3°.

Driving of bolts is not permitted.

If, after final tightening, a nut or bolt is slackened off, it must not be used again.

Higher grade (waisted shank) bolts BS 4604 may be used in joints subject to tension as well as shear, using the part turn method of tightening. Tightening by the torque control method is not permitted.

## Applications and Advantages

Used on road bridges, structural repairs and extensions, heavy installations subject to vibration, power station work and colliery winding gear.

H.S.F.G. bolts have virtually replaced hot driven rivets for fastening steel structures on site. They are also used to replace defective rivets on repair work.

Where structural members are shop assembled, welding is still more economical on the whole, but certain connections are better bolted and the difficulties encountered with site welding are eliminated when H.S.F.G. bolts are used.

System-built factories and offices are particularly suitable for H.S.F.G. bolts.

Compared with riveting, fewer H.S.F.G. bolts are needed than rivets for a given joint, and fewer men in the team needed to put them in, two against three or four. Less noise, simpler assembly (approximately three times faster than riveting), simpler inspection, and no fire risk. A smaller safety factor may be allowed than for riveted structures. On the whole, the cost is less using H.S.F.G. bolts.

**Note:** It is important that the torque on the nuts is correct for the bolt, so a pre-calibrated impact wrench is used, or the part turn method, or a feeler gauge if load indicating bolts or washers are being used. Bolts must be tightened in a definite sequence.

**Clearance** The diameter of the bolt hole is usually 1.6 mm larger than the nominal diameter bolt shank.



## Washers

### General

In all cases where the full bearing area of the bolt is to be developed, the bolt should be provided with a steel washer under the nut. This washer must be of sufficient thickness to avoid any threaded portion of the bolt being within the thickness of the parts bolted together and to prevent the nut, when screwed up, bearing on the shank of the bolt.

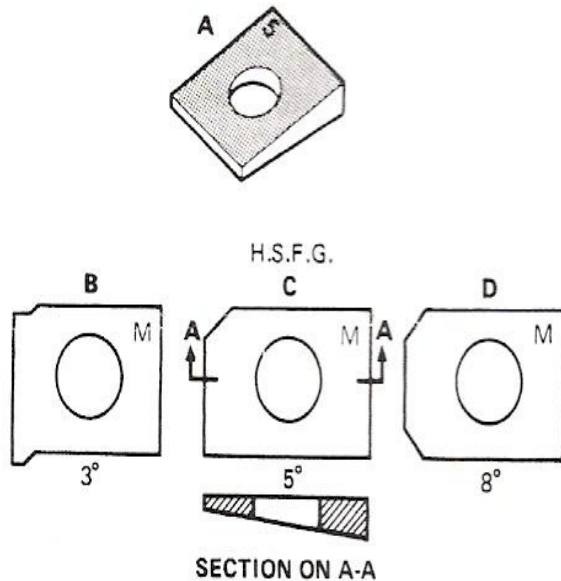


Figure 44

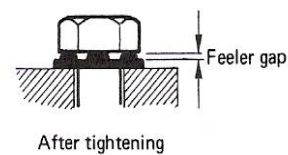
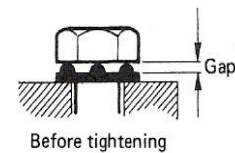
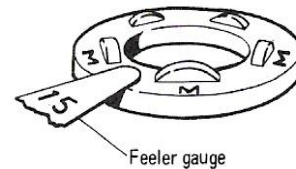


Figure 45

### Taper

(Figure 44)

These washers should be placed under the nut or head of any bolt bearing on any bevelled surface. The angle of taper on the washer should match the angle of taper on the section. Washers are invariably marked with the angle of taper, i.e. 3°, 5° or 8°, or with the type of corner on H.S.F.G. taper washers (types B, C, D in Figure 44).

### Load Indicating Type “Coronet”

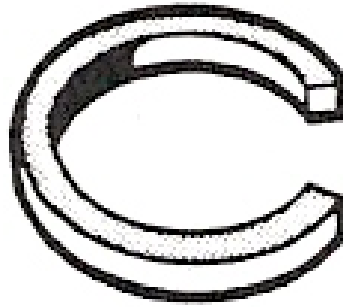
(Figure 45)

The "Coronet" Load Indicator is a specially hardened washer with protrusions on one face. The protrusions bear against the underside of the bolt head leaving a gap. As the bolt is tightened the protrusions are flattened and the gap reduced. At a specified average gap, measured by feeler gauge, the induced shank tension will not be less than the minimum required by Standards.

### Spring Types

(Figure 46)

Where vibration is likely to be present to any degree in a fabrication, the nuts should be used with some form of spring washer to prevent the nut unscrewing during service.

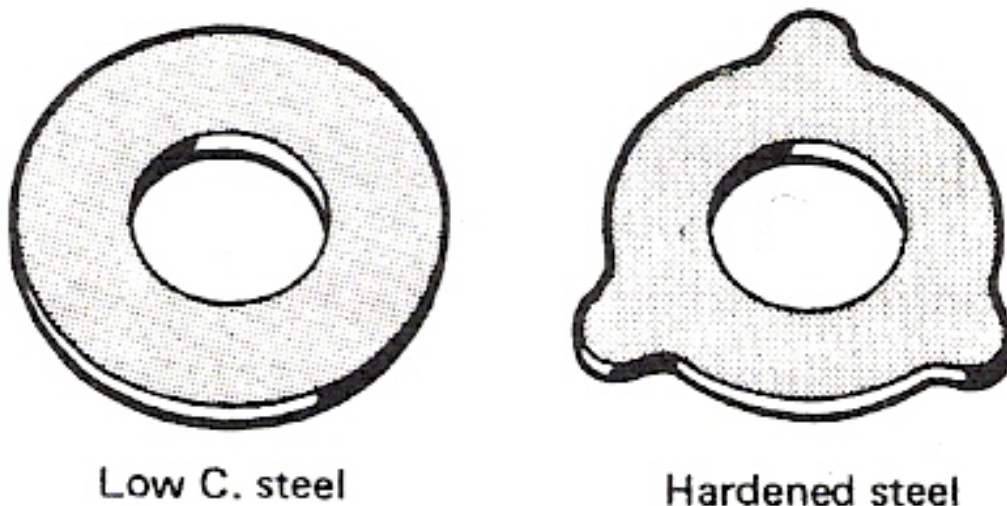


**Figure 46**

### Flat Type

(Figure 46, Figure 47)

Ordinary flat, low carbon steel washers are just punched into shape without further work but washers for turned barrel bolts are machined and should have a hole diameter not less than 1.6 mm larger than the barrel thickness and a thickness of not less than 3.2 mm so that the nut will not bear on the shoulder of the bolt. Flat washers for H.S.F.G. bolts are made from low alloy steel and are extremely hard and may be distinguished by the three tabs on the outer edge (Figure 47).



**Figure 47**

## **Health and Safety/Hazards Associated with Fabrication**

The legal requirement of the new Health and Safety at Work Act 1974 has created for both employers and employees a more acute awareness of the need to take care in avoiding accidents, injury and disease. The Act states: "It shall be the duty of EVERY employee while at work to take reasonable care for the health and safety of himself and of other persons who may be affected by his acts or omissions at work" (e.g. screening of the arc, wearing goggles, grinding and chipping away from others, replacing guards, keeping gangways clear, marking hot metal, etc.).




It is the duty of the employer to ensure that adequate protective equipment is available, and that adequate guarding of machines is maintained so that they are SAFE when PROPERLY USED (mechanical and photo-electric).

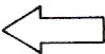
The employee (you) is required by law to wear certain protective devices in designated areas, for example eye protection. In addition to protective equipment such as helmets, goggles, spectacles, visors, ear muffs (noise), gloves, fireproof aprons and spats, toetector boots, etc. there are other factors to be considered to ensure your health and safety.

### **Factors to be Aware of to Avoid Injury**

1. Never line up holes with your fingers.
2. When using rotating machines (drills), beware of hanging hair, ties, clothing, scarves or belts getting caught.
3. Lift weights correctly with a straight back using the strength of leg and beware of sharp edges (gloves). Rings should not be worn.
4. Know where the first aid room, the nearest phone, the fire alarm and fire extinguishers are.
5. Lift gas cylinders with rope slings and do not use as rollers.
6. Be aware of electrical hazards such as bare wires, poor earth return connections, wet floors (use duck boards to stand on).
7. Do not use oxygen as a substitute for compressed air and never use as a "sweetener" in compartments where the air is stale.
8. Do not use compressed air to blow down clothes as the pressure can cause serious injury to eyes, ears and internal organs.
9. Stack plate, sheets or components tidily and not too high.
10. NEVER remove guards whilst a machine is running (it is illegal) and know where the STOP button is. Do not start a machine without guards in position.

11. Keep your work place clean and tidy and don't use defective tools.
12. Do not fool around in the workshop and always walk not run.
13. Know the warning signs and safety colours and watch out for them.
14. Know your crane signals (see Figure 48).
15. Use ventilation equipment to avoid dangerous concentrations of oxides of nitrogen, ozone, fumes from metals such as lead, zinc and cadmium. The following solvents also give off dangerous vapours: benzene, carbon tetrachloride, trichloroethylene and perchloroethylene (poisonous phosgene gas). Never allow the following to come in contact with the skin: lead paint, corrosive acids, paraffin or oils.
16. Learn the different types of fire extinguisher.

CIRCLE		An order
TRIANGLE		Caution
RECTANGLE		Safety information

Red	Obstruction
Orange-yellow	(Tiger stripes Hazard with black diagonals)
Green	Safe route 



Signaller should stand in a secure position where he **CAN SEE** the **LOAD** and **CAN BE SEEN CLEARLY** by the driver  
Face the driver if possible. Each signal should be distinct and clear.

Figure 48 - Crane Signals

**Signals are important to know if walkie-talkie/phones are not available.**

## Fire Fighting

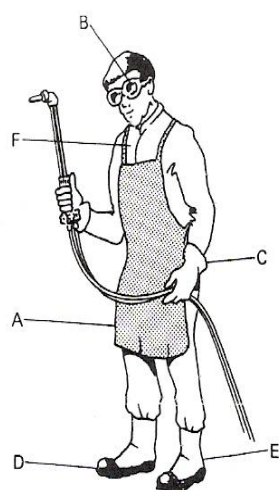
The following table shows the three main classes of fire and the approved fire extinguishing media.

<i>Class of Fire Risk</i>	<i>Type of Extinguishing Agent</i>	<i>Notes</i>
<b>Class A</b> Wood, cloth, paper and similar solid combustible material	Water from fire buckets, hose reels, extinguishers of the gas pressure and soda/acid types	This employs the cooling-down method which reduces the temperature involved to below that of combustion
<b>Class B</b> Flammable liquids—petrol, oils, greases, fats	Asbestos blankets	Suitable for small fires, e.g. frying pans
	Dry powder	Suitable for fires in spilled liquids when quick control is required
	Carbon dioxide (CO <sub>2</sub> )	Quick acting, clean, does no damage and is non-conductive
	Foam	Smothers the fire and seals against re-ignition
<b>Class C</b> Electrical equipment	Dry powder Carbon dioxide (CO <sub>2</sub> ) Vaporising liquids	All are non-conductive. Water <i>Must Never be Used</i> . Carbon dioxide causes no damage to delicate equipment

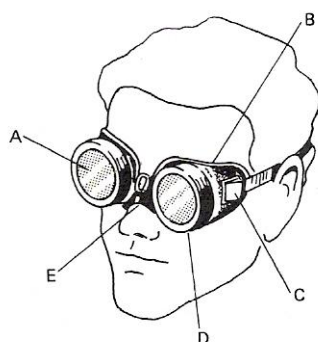
**Table 1 - Classes of Fire Risk**

## Protective Clothing and Equipment

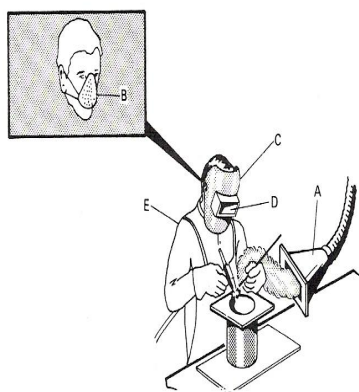
The following figures illustrate examples of the use of protective clothing and equipment.



<i>Name</i>	<i>Main Use</i>
A. Flame-resistant apron	Prevents burning of clothes.
B. Gas welding/cutting goggles	Protects eyes from sparks.
C. Gauntlets	Prevents skin burn.
D. Safety boots (steel toecap)	Prevents crushing of toes.
E. Spats	No molten metal down boots.
F. Boilersuit	Protects neck and chest



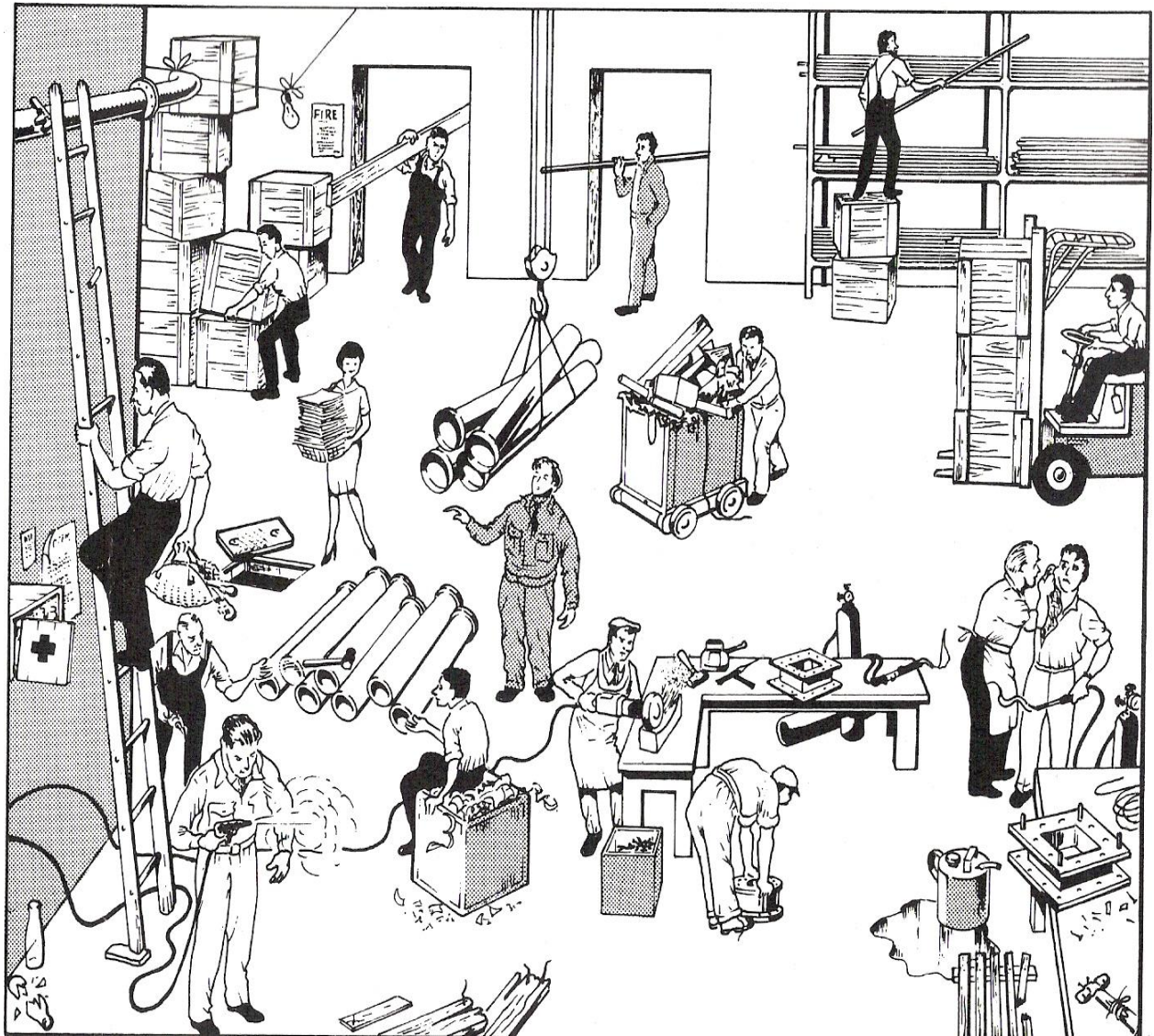
<i>Name</i>	<i>Use</i>
A. (i) Clear glass	Protects tinted lens.
A. (ii) Tinted lens	Limits glare.
B. Goggle body	Stops sparks.
C. Air vent	Prevents misting up.
D. Lens holder	To change broken lens.
E. Strap adjustor	Adjust for size.



<i>Name</i>	<i>Use</i>
A. Extractor fan	Takes away fumes.
B. Filter mask	Dust and fumes.
C. Head shield	Prevents skin burn.
D. (i) Renewable clear glass	Takes spatter, etc.
D. (ii) Renewable tinted	Prevents arc eye.
E. Leather cape with sleeves	For overhead work.

The filter mask (last figure, B) is no protection from dangerous gases such as phosgene (which is formed from degreasing agents such as trichloroethylene) or nitrous fumes (caused when large areas of plate are heated) or any other poisonous gases.





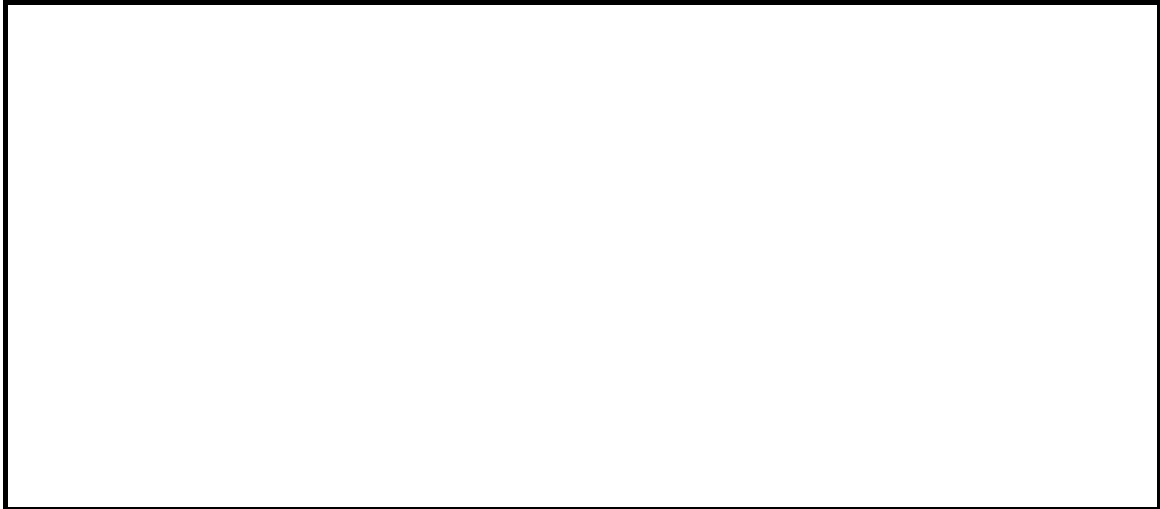
**Figure 49 - List as Many Instances of Unsafe Practice as you can Detect**

*Courtesy "What's Wrong" Safety Posters)*

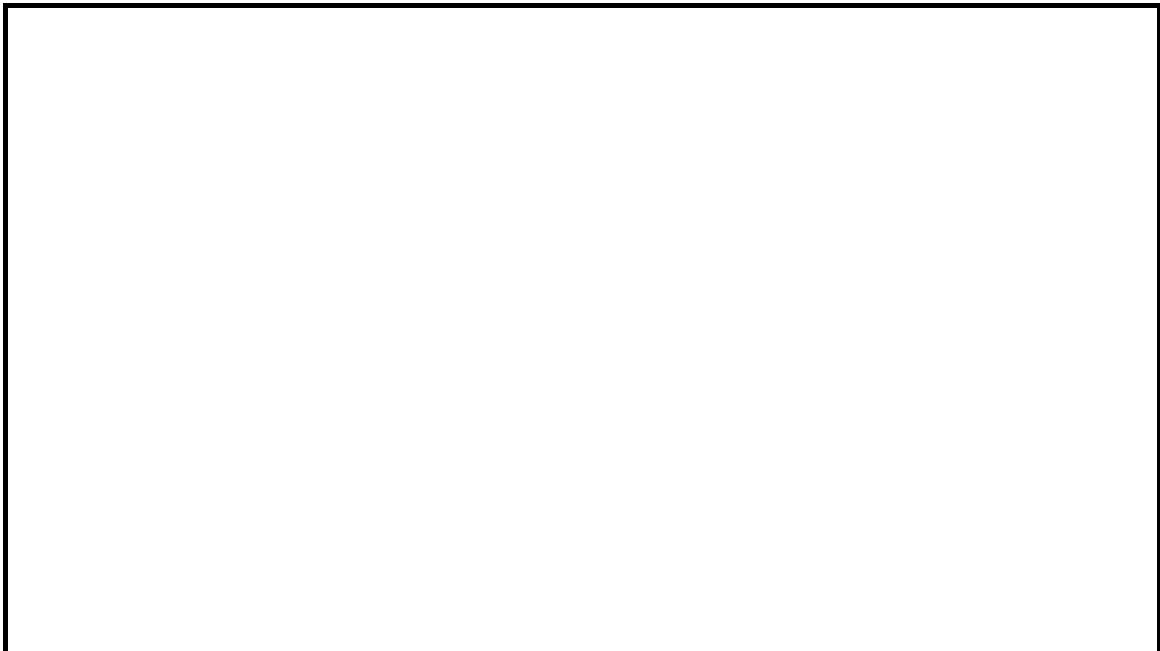
## Self Assessment

Questions on Background Notes – Module 4.Unit 9

1. In relation to the testing of Structural Steels, what is a Destructive Test?

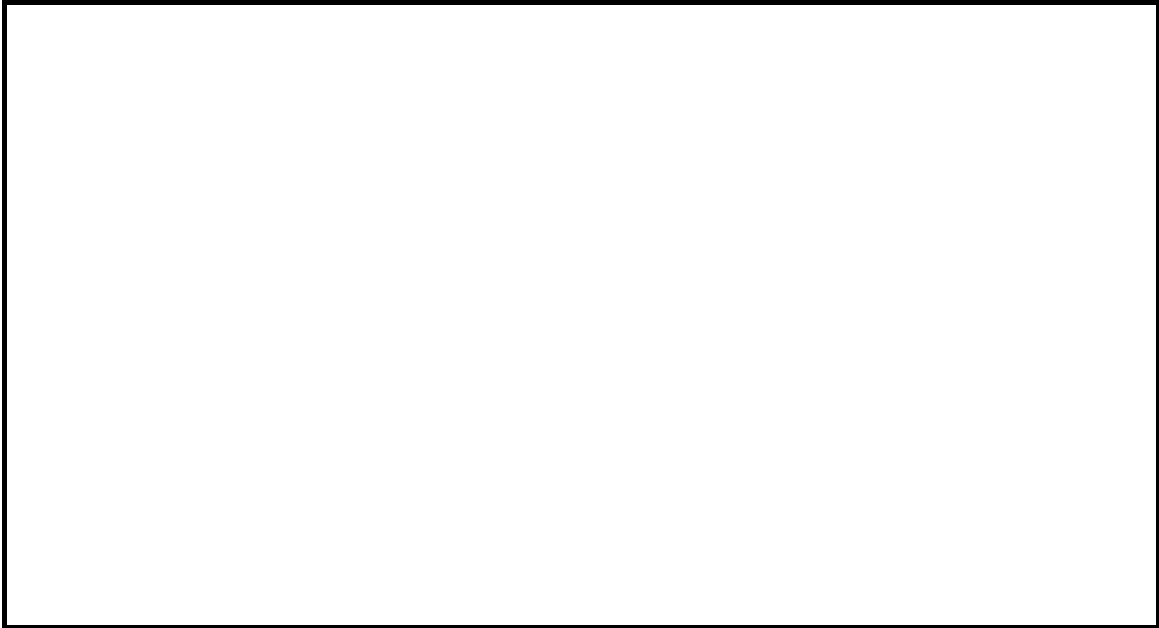


2. In relation to the properties of Metals, what do the terms Brittleness and Tensile Strength mean?

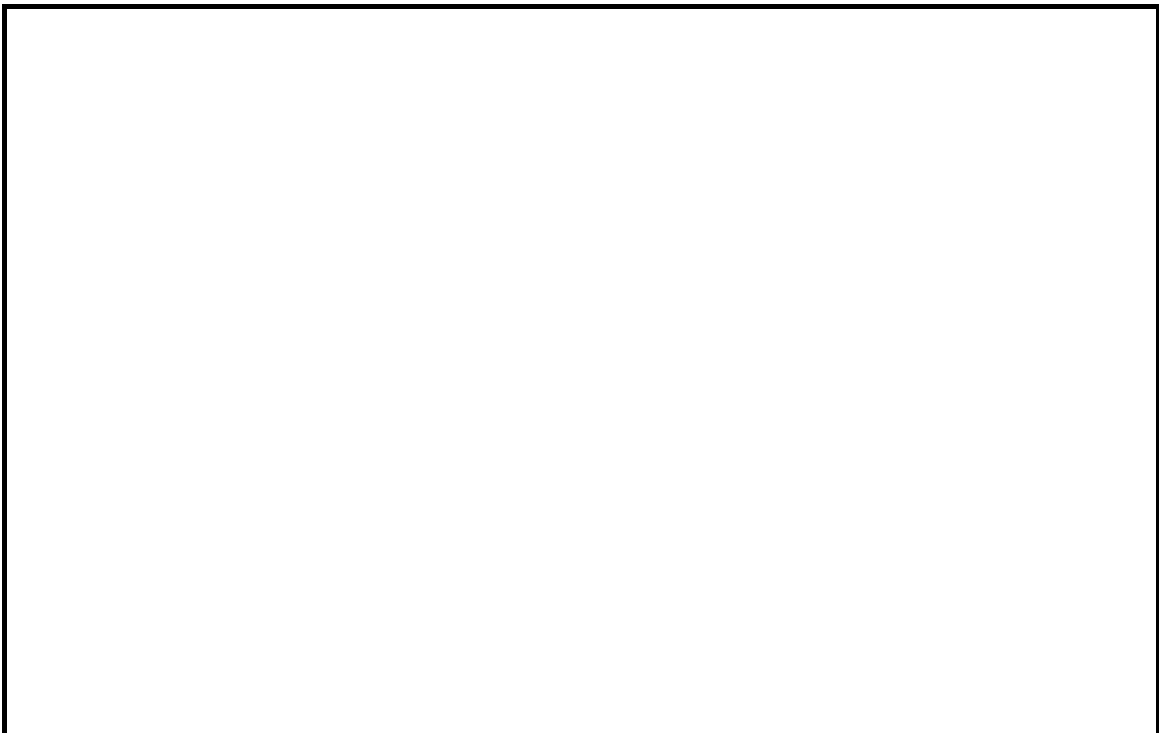




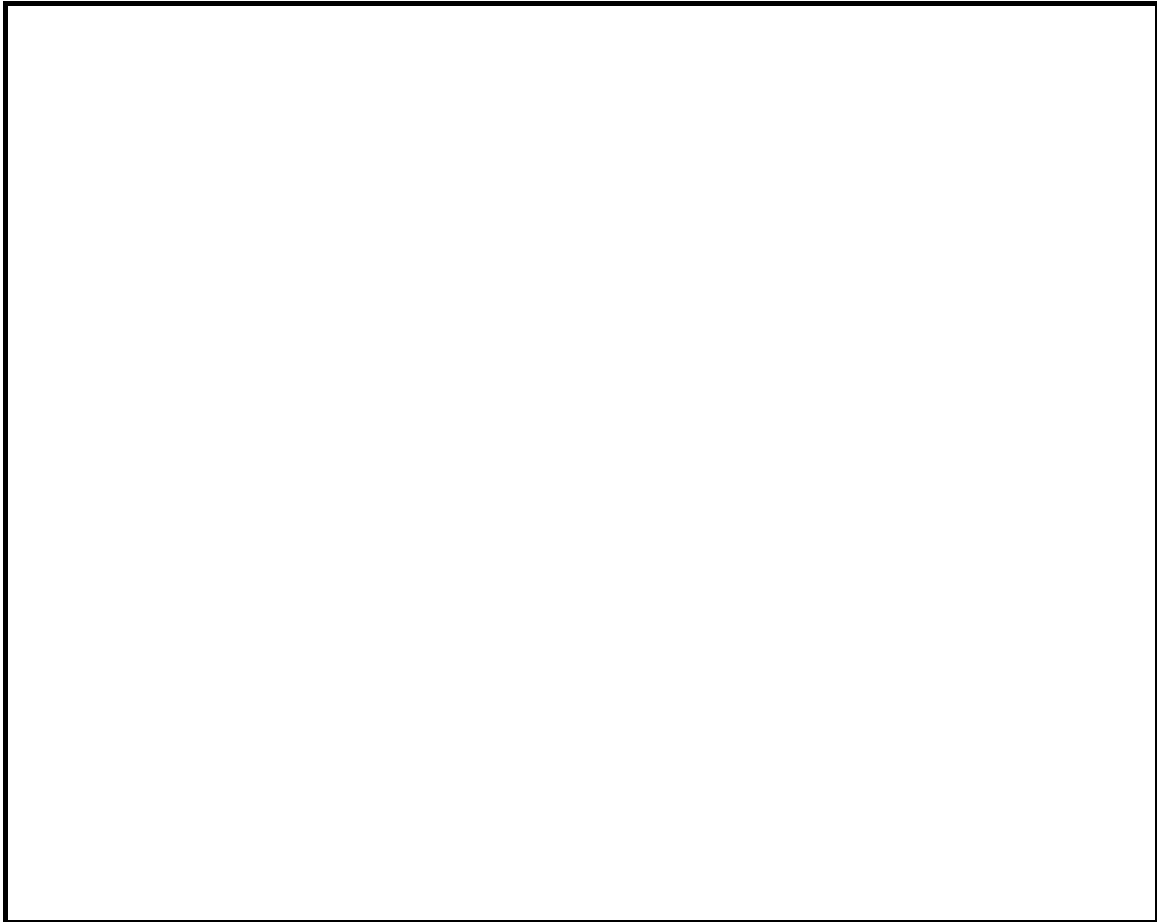
3. Briefly explain the term 'Impact Strength'.



4. In relation to the structure of metal, what is meant by Grain Growth?



- 5.** List some Health and Safety factors associated with the Metal Fabrication Trade and three points to be aware of to avoid injury.



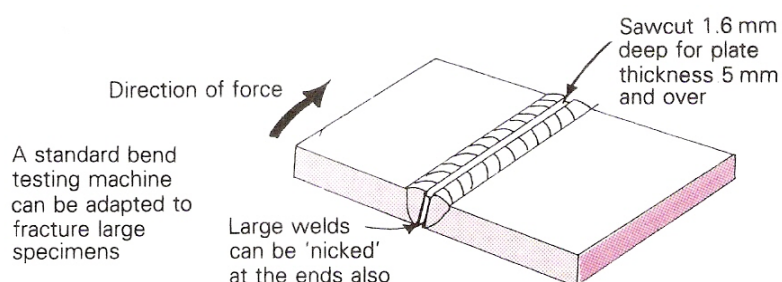
## Answers to Questions 1-5. Module 4. Unit 9

1.

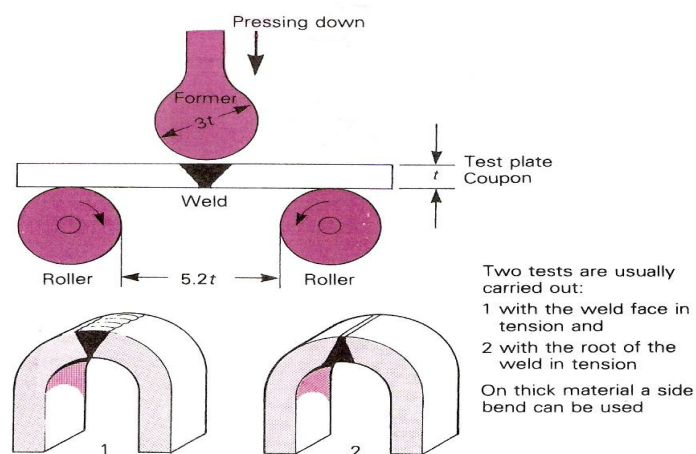
### Destructive Testing:

Many of these tests (such as the bend test and tensile test) will fail if there are internal defects present. Other tests, such as the nick break test break open the weld so that we can see inside it. The macro-etch test will show fusion faces and internal defects.

**Figure 10: Butt Weld Specimen Prepared for a Nick Break Test.**



**Figure 11: Principle of the Bend Test.**



2.

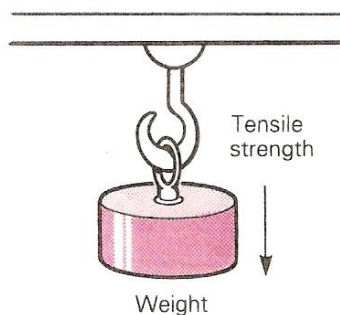
### **Brittleness:**

This is the opposite of plasticity. It refers to a metal's tendency to break suddenly when under load, without any appreciable deformation. Many metals in their cast state will fracture when subjected to a large enough impact. In some metals, an increase in temperature can reduce brittleness, while in others it can increase it. For example, copper is a ductile metal, but it becomes brittle near its melting point. In general most metals become less brittle when you apply heat to them. You should take special care when welding brittle metals, because of their lack of ductility.

### **Tensile Strength:**

This measures a metal's ability to withstand a stretching load without breaking. Another name for tensile strength is Tenacity.

**Figure 12:**

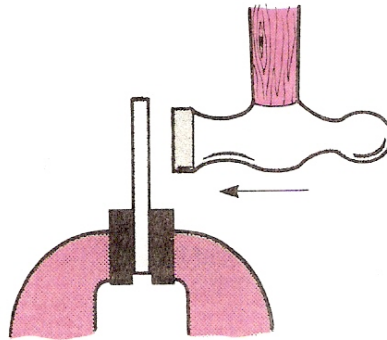


3.

**Impact Strength:**

This measures a metals ability to withstand impact.

**Figure 13:**



4.

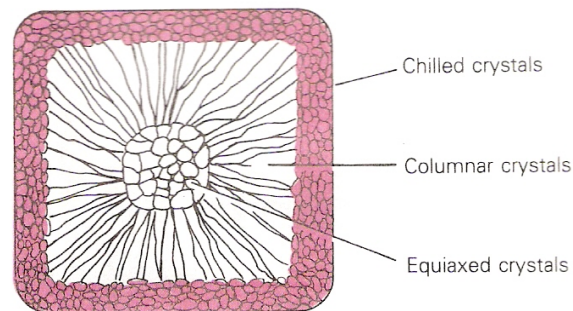
**Grain Growth:**

The rate at which a metal cools will affect the number of nuclei formed; slow cooling will promote the growth of fairly few nuclei. The result is that the crystals (or grains) will be large enough to be visible without the aid of a microscope. Fast cooling will promote many nuclei and a small fine-grain structure.

In a large ingot of cast metal or a large weld, the crystal sizes can vary considerably from the outer edges to the centre. This is due to variation in the temperature gradient, because as an ingot or a large weld solidifies, heat will be transferred from the metal to the mould (or the heavy parent material).

#### 4. Continued.

**Figure 14:** An Ingot of a Pure Metal Showing the Crystal Structure.



When the metal first makes contact with a cold mould there is a chilling effect and many small crystals form. As the mould warms up the direction of cooling is mainly inwards and extremely elongated columnar crystals are formed. As heat is lost still further, the metal in the centre begins to form its own nuclei and a third type of crystal is formed, showing no preference for directional growth.

5.

**Health and Safety:**

- Never line up holes with your fingers.
- When using rotating machines (drills), beware of hanging hair, ties clothing, scarves or belts getting caught.
- Lift weights correctly with a straight back using the strength of leg and beware of sharp edges (gloves). Rings should not be worn.
- Know where the first aid room, the nearest phone, the fire alarm and fire extinguishers are.
- Lift gas cylinders with rope slings and do not use as rollers.
- Be aware of electrical hazards such as bare wires, poor earth return connections, wet floors (use duck boards to stand on).
- Do not use oxygen as a substitute for compressed air and never use as a "sweetener" in compartments where the air is stale.
- Do not use compressed air to blow down clothes as the pressure can cause serious injury to eyes, ears and internal organs.
- Stack plate, sheets or components tidily and not too high.
- NEVER remove guards whilst a machine is running (it is illegal) and know where the STOP button is. Do not start a machine without guards in position.

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