Trade of Metal Fabrication

Module 1:	Basic Fabrication
Unit 9:	Forging, Casting and Extrusion
	Phase 2

Table of Contents

List of Figures

List of Tables

Document Release History

Date	Version	Comments
17/08/06	First draft	
13/12/13	SOLAS transfer	

Module 1 – Basic Fabrication

Unit 9 – Forging, Casting and Extrusion

Duration – 4 Hours

Learning Outcome:

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

- State the advantages and limitations of the casting process with specific reference to sand casting.
- Describe the effect of forging on the properties of metals.
- Describe the difference between hand forging, steam hammer, hydraulic press and drop forging.
- Describe a blacksmith's hearth and the equipment and tools used for forging.
- Describe common decorative forgings and their uses.
- Describe the difference between blacksmith and farrier.
- Describe the uses of the hebo machine.
- Describe extrusions and their uses.

Key Learning Points:

Rk	Sand casting - different uses.
Rk	Advantages and limitations of casting process.
Rk	Forging effects on the properties of metals.
Rk	Methods of forging.
Rk	Forge equipment and tools.
Rk	Decorative forgework/ornamental ironwork - artwork.
Rk	Blacksmith/farrier.
Rk	HEBO machine.
Rk	Extrusions.
Rk H	Safety.
P	Communication - quality awareness.

Training Resources:

- Classroom
- Instructor lectures, handouts, notes and texts
- Videos

Exercise:

Question and answer session.

Key Learning Points Code:

M = Maths D= Drawing RK = Related Knowledge Sc = Science

P = Personal Skills Sk = Skill H = Hazards

Tinman's Heads and Stakes

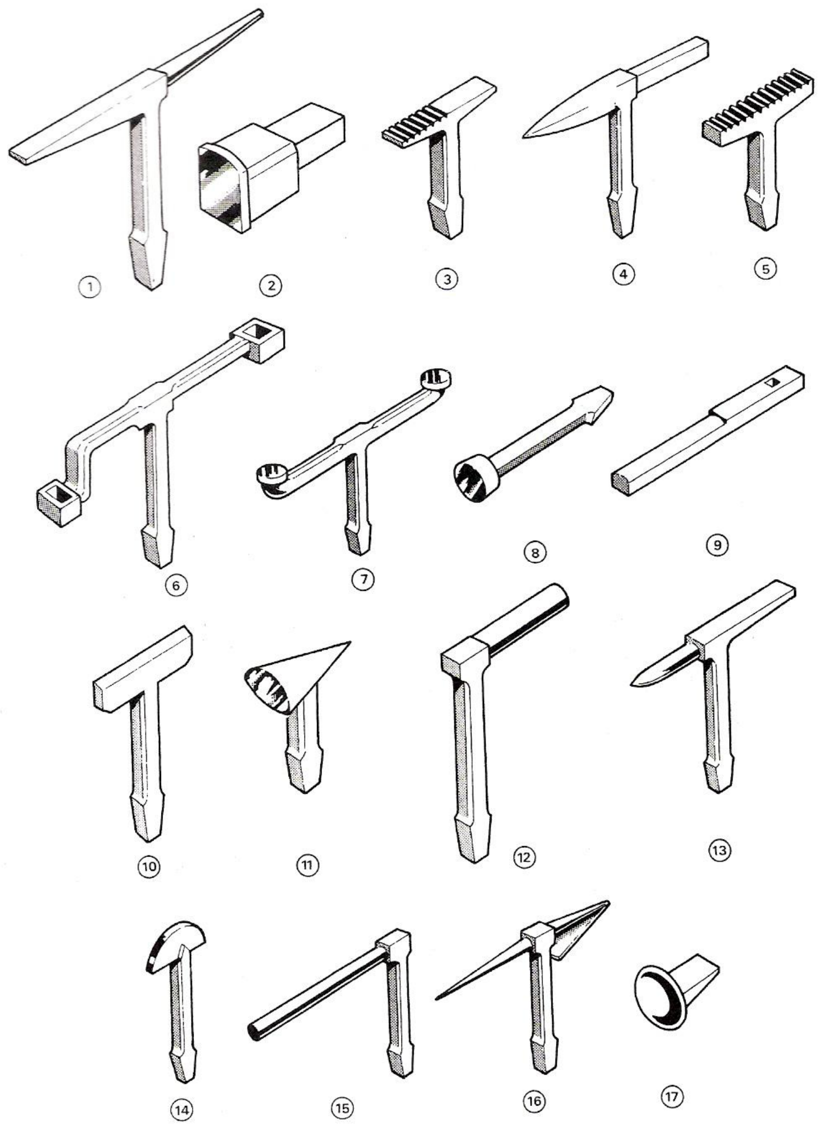


Figure 1 - Tinman's Heads and Stakes

A selection of the more commonly used heads and takes. Stakes are manufactured from steel forgings, heads from cast steel or cast iron.

1. Bick Iron
2. Anvil Stake
3. Creasing Iron
4. Combined Funnel and Side Stake
5. Grooving Stake
6. Horse
7. Saucepan Belly Stake
8. Round Bottom or Canister Stake
9. Tinman's Mandrel
10. Hatchet Stake
11. Funnel Stake
12. Side Stake
13. Extinguisher Stake
14. Half-Moon Stake
15. Pipe Stake
16. Blow Horn Stake
17. Oval Horse Stake

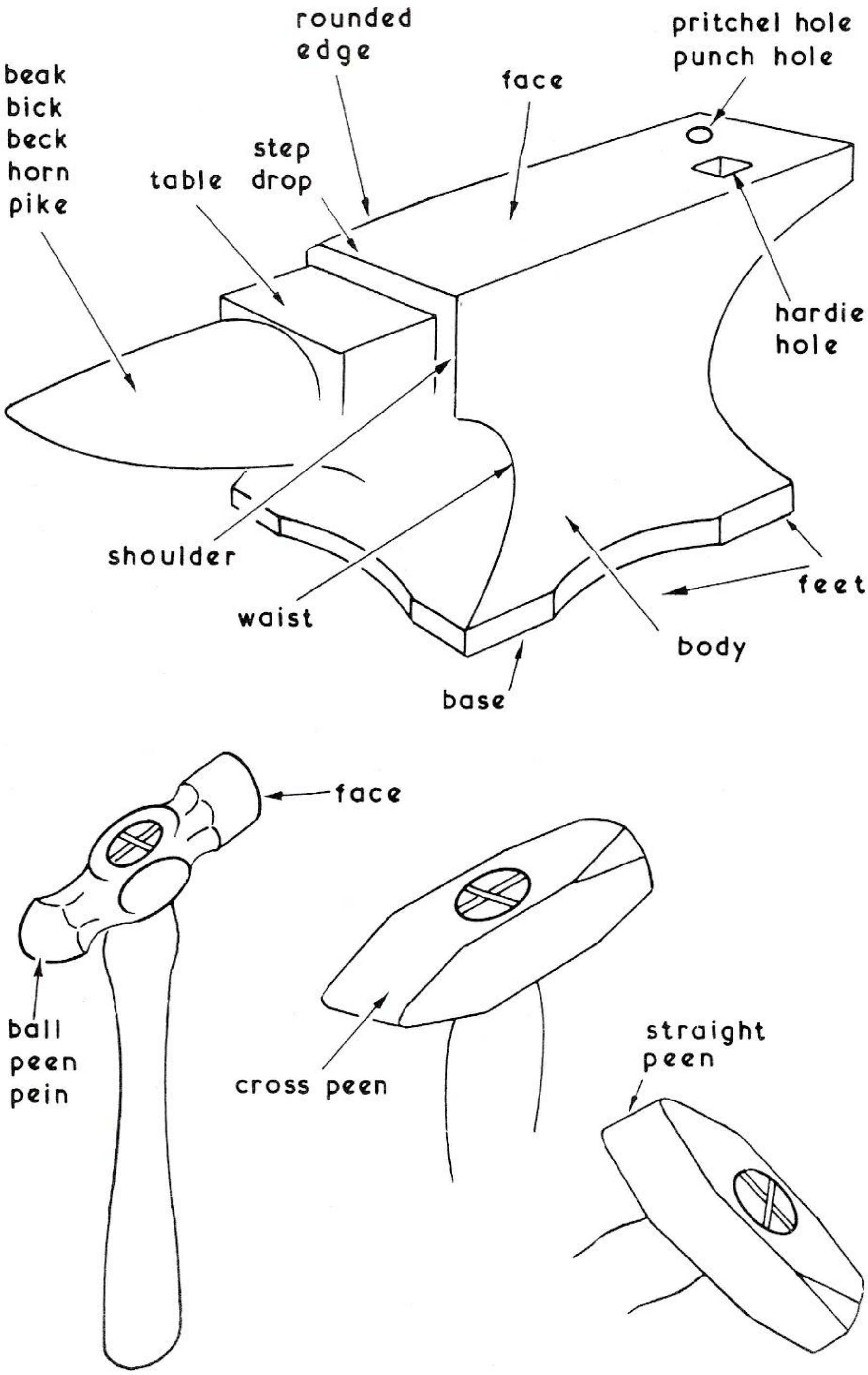


Figure 2 - Names of the Main Parts of the Anvil and Hammers

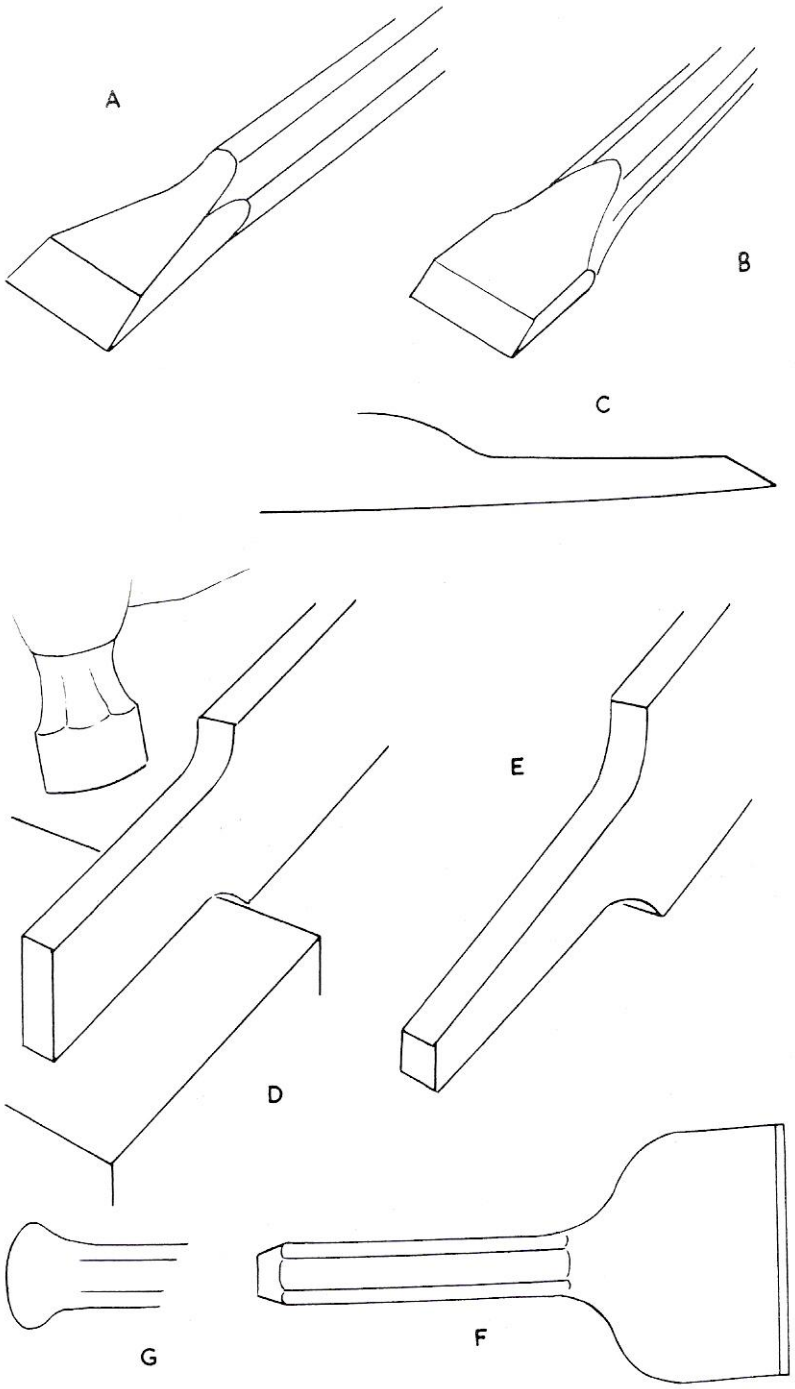


Figure 3 – Chisels

For a wider edge, rod can be widened or wide bar can be reduced.

(a) Chisel with tapered sides

(b) Parallel sides

(c) The blade blends into the rod

(d) Draw out

(e) Use fullers and draw out more

(f) Make a grip

(g) Round the grip

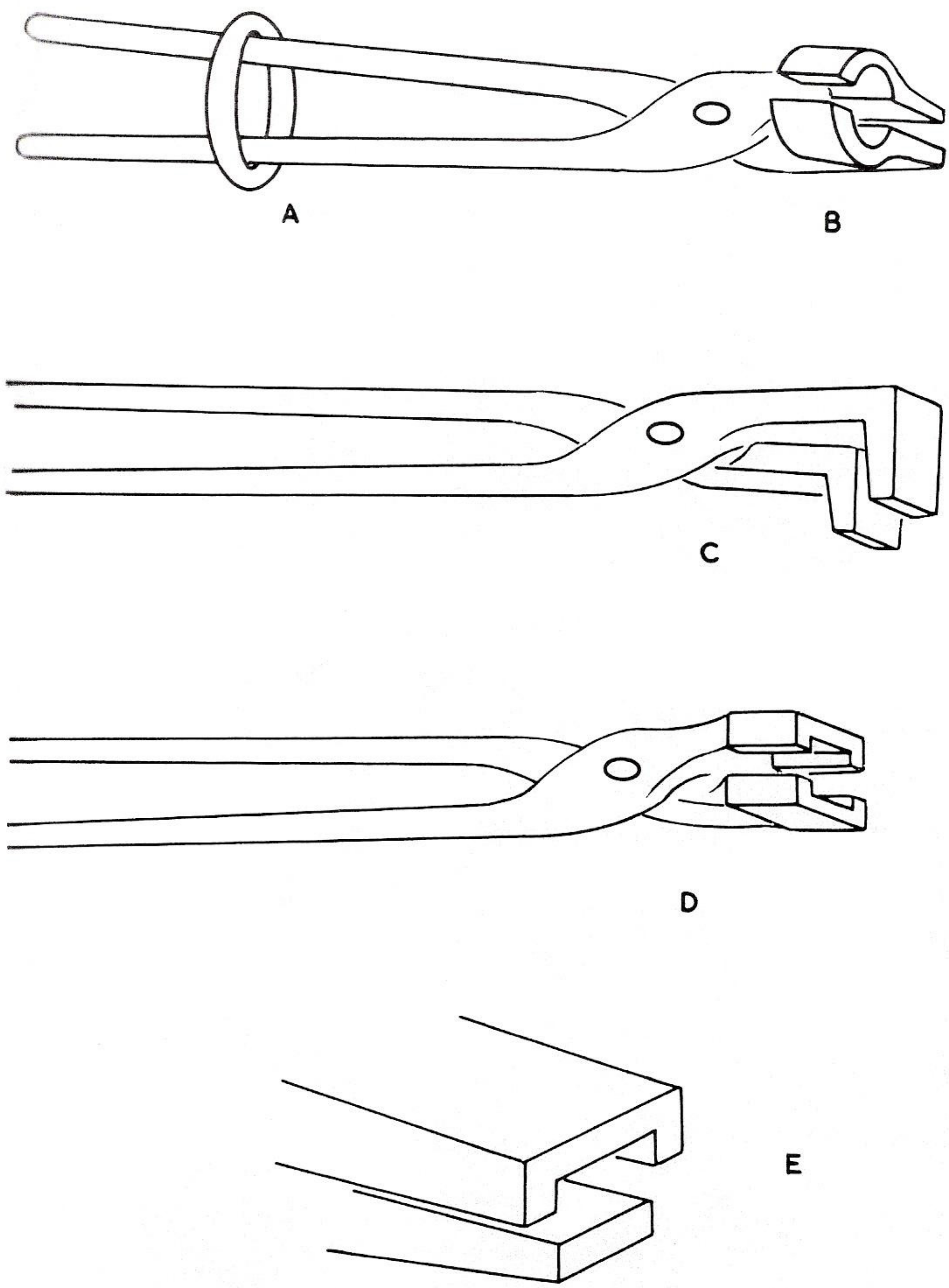


Figure 4 – Tongs

Special tongs hold steel at an angle. Any tongs can be locked on with a ring.

(A,B) Bent-bit or side tongs

(C) Side-bit tongs

(D) Box tongs

(E) Semi-box tongs

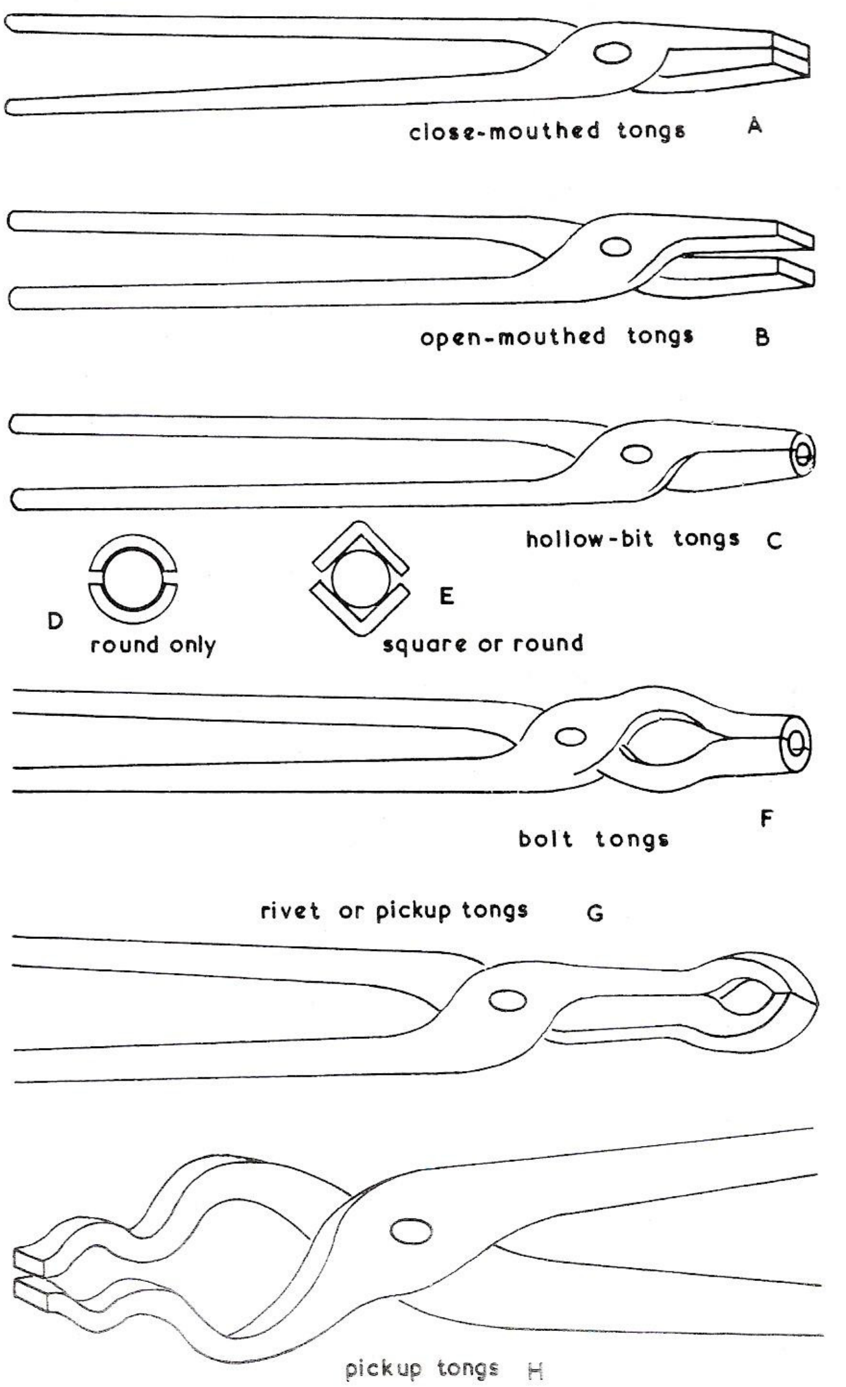


Figure 5 - Tongs Jaws

Tongs have their jaws shaped to suit many purposes.

Decorative Ironwork

Much of the skilled and artistic work done by blacksmiths in the last few centuries can be seen in gates, railings, grills, church screens, and similar objects where the assembly was a mass of individually shaped parts joined together to make a pleasing pattern. In some cases, the blacksmith's work was linked with cast iron. There are a great many surviving examples of work executed entirely by the smith at his forge with quite simple equipment. His skill and creativity were his most important tools. He could not call on precision machinery, and any jigs used were made by the blacksmith himself as needed.

The material was iron, and the type of work is collectively called wrought-iron work.

The work wrought in this instance is used in the sense of meaning worked, although the material was also called wrought iron.

Some modern wrought-iron gates and similar things are very different from the traditional work. They are made of bars all of a uniform section. The majority of parts in a traditional piece of wrought-iron work, on the other hand, are tapered and twisted and changed section in their length to get the effect the smith wanted. The scrolls of modern work are not very thin and are all identical, showing that they were pulled cold around standard shapes, probably in a machine. Although such gates and other assemblies might be attractive, they are machine-age imitations of the products of real craftsmen.

Like many seemingly complex things, a gate or length of railings is built up from a series of comparatively simple steps. If the steps are understood and each performed properly, the final assembly should be very satisfying. Although the assembled construction might be quite heavy, the individual parts are not. There are some stages where a helper is essential, but much of the work can be done single-handedly. The amount of heat required at any time is not great and a small hearth should be adequate. It is always easier to work on a large anvil, but if the work is schemed to suit, much of the shaping can be done on a small anvil. For some of the details, such as twisted leaves, a small anvil might actually be better than a large one.

Much of the work involves applying techniques already covered in earlier chapters.

If you think about what is happening to the steel when you hit or bend it, almost anything is possible as you direct your blows to get the best effect and the maximum result from each action.

Look at examples of wrought-iron work made by a blacksmith. If you cannot find an actual gate or similar object, examine photographs. Old churches might have a gate or screen. After you have enjoyed the object as a whole, look at some of the details. Try to visualize how various pieces were made. Notice how the parts are joined. See how sections have been changed, how the smith has thinned sections down to make ornamental twists and twirls. Look at the ends of scrolls (Figure 6) and other parts. There are a large number of ways of shaping the ends before curling them. Think out the shape that was made before the end was rolled tightly. Finishing an end in the form of a leaf is common (Figure 7). Note how the bar is thinned, shaped, and twisted or crinkled in leaf form. Look for the leaf veins that have been cut in it (Figure 8).

Scrolls

The tip of a scroll (Figure 9, Figure 10 and Figure 11) in blacksmithing is always given some sort of decoration, usually in the form of a tight roll on the end of the drawn-out bar. A machine-made modern scroll has the bar of the same thickness throughout and no rolled end. Some ways of dealing with the ends have previously been described, but these and others are summarized in this chapter.

Most decorative work of this sort is done with flat-sectioned bar. Round rods and square sections also have their uses but most work is done with a bar that is about twice as wide as it is thick. Practice with a bar of this section. First make sure you can draw it down with an even taper almost to a chisel end (Figure 12A). Get as good a shape as you can under the hammer, but use a flatter if necessary. You should be able to get a graceful taper over a long length as well as a short length.

It is possible to curl the end almost entirely by hammering. Have the end at a yellow heat and use a light hammer while the bar is held across the anvil face. Hitting progressively with glancing blows on the end should curl the thin metal tightly (Figure 12B). There might have to be occasional moves to the flat of the face to straighten and maintain the thickness, but it should be possible to get a tight curl on a light bar with one or two heatings. The thin end loses its heat quickly, but it also takes up heat quickly. Be careful not to leave it in the fire too long that the end melts off.

A tight curl is not always wanted throughout; it usually looks best if the inner curl is close. Afterwards the small scroll can become more open (Figure 12C). Hit further back to make the curves longer (Figure 12D).

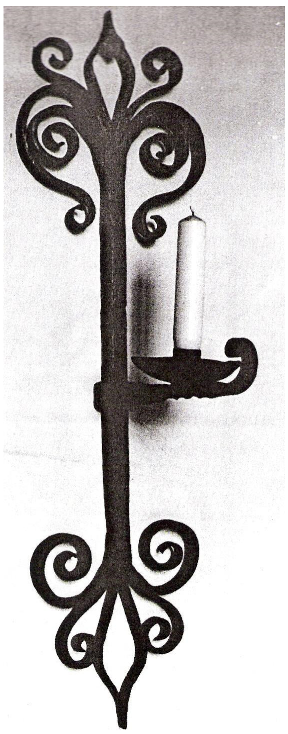


Figure 6 - Candle Sconce Shows Applications of Simple Scrolls

Some smiths make snub ends with solid centres (Figure 12E). Besides being considered more attractive, the snub helps in the early stages of making a large scroll. To make a snub end, have rod of suitable size and cut it almost through at a length slightly more than needed. Start a curve on the bar, then heat both parts to welding heat and hammer them together (Figure 12F). Snap off the unwanted rod. The welded piece of rod can be hammered on the ends, or might have to be filed or ground later.

Figure 7 – Stylised Leaves

The scrolls in this gate have their ends flattened to make stylised leaves.

In much wrought-iron work, the ends of scrolls are not parallel. They can be wider than the bar, whether welded to a snub or the thin end curled alone. If the end is drawn down in the width as well as the thickness, the scroll end gets narrower (Figure 12G). If it is flaired out toward the end, an interesting effect is achieved (Figure 12H). It could be narrowed and then flaired so a narrow neck leads up to the roll (Figure 12J).

A scroll can be just a part of a circle, or it can go around several turns in a spiral.

Skill comes in getting the curves even and in keeping distances between the turns the same or at a regular rate of increase. This is complicated by the fact that in many assemblies there are a large number of scrolls that should be the same. Machine-like perfection is not wanted, but there should not be great differences between scrolls that are designed to be the same. Much of the skill is in the eye and hands of the smith, but there are some tools to help.

One tool is a block of steel that fits in the hardie hole and is called a *halfpenny snub end scroll*. The curve in the side is about the same as an old English halfpenny (pronounced "haypnee") and about 1 inch across. It is used with somewhat heavier bar than can be hammered across the anvil, and the tapered end is formed with a curve on it (Figure

13A). It can be used with a tapered end, but it is particularly suitable for a bar with a snub end (Figure 13B).

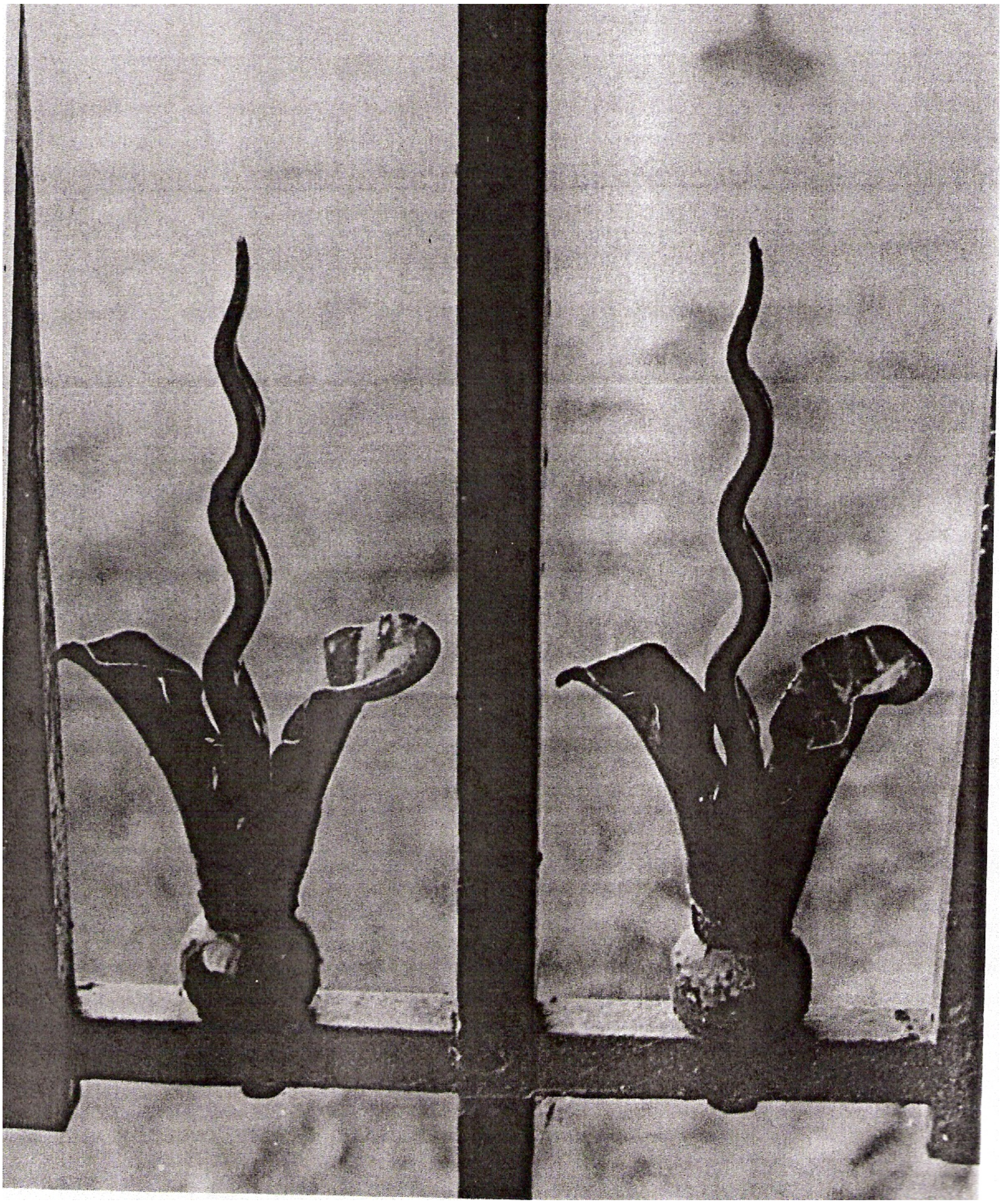


Figure 8 – Flamelike Centre

Sheet steel is formed into leaves around a drawn-out flamelike centre in each decoration.

Figure 9 – Old Uneven Scrolls

These old scrolls appear to have been made by a smith without the aid of a scroll iron, because they are uneven in shape and thickness.

Another tool is a scroll starter (Figure 13C). It can be held in the vise or provided with an end to fit the hardie hole. The steel has its end curled so as to hold the thin end of the starter, and then the hot steel is pulled to the curve.

To get a number of scrolls to match, a smith can make a scroll iron or tool (Figure 13D). This is a scroll made of steel stout enough not to pull out of shape when bar is pulled around it. The centre of it is thinned and curled to take the prepared end of the work. It also eases engaging the hot steel, which can be locked on there and quickly pulled around as far as the required scroll has to go. Not every scroll made has to go the whole way. Usually the scroll tool end is turned down and either fits the hardie hole or is held in a vise.

Scrolls can be worked with a scroll fork and a scroll wrench. The scroll fork stands with its end upward in the hardie hole or vise, and the scroll wrench is used to lever the curves in the hot steel (Figure 13E). With the horizontal action, it is possible to see how the shape is coming and make adjustments even after you have passed a particular point.

Figure 10 – Scrolls and Leaves

This church gate shows how scrolls and leaves can be built up into a very effective whole design.

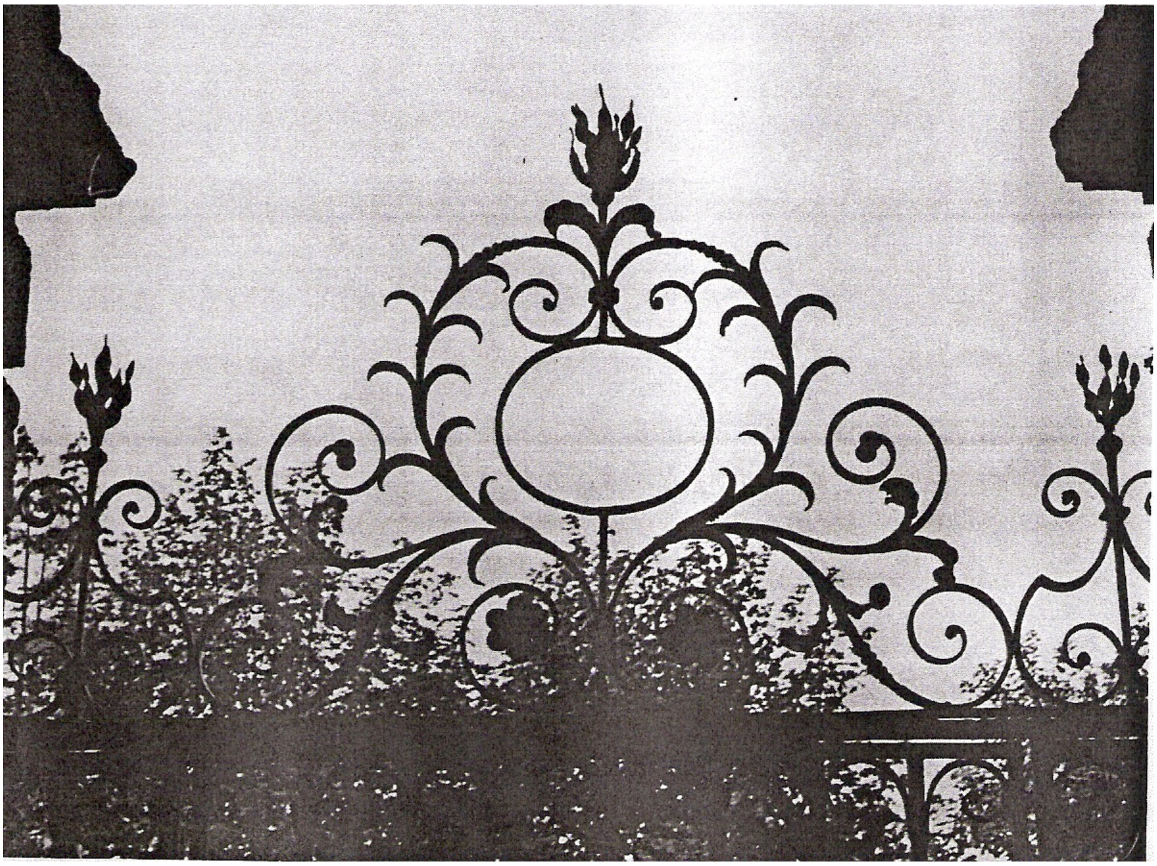


Figure 11 – Gate Apex with Flame Effect

The top of the previous gate showing how the design rises to an apex with flame effect at the peak.

Scrolls are best tackled boldly, with the whole length of the shape heated and pulled or hammered around quickly. In wrought-iron work, many scrolls are enclosed in other parts, so they have to be carefully worked to match a drawing. This is particularly so if both ends of the same piece are scrolls, the same or opposite ways (Figure 13F and Figure 14). If the end is free from anything around it, exact sizes are not so important.

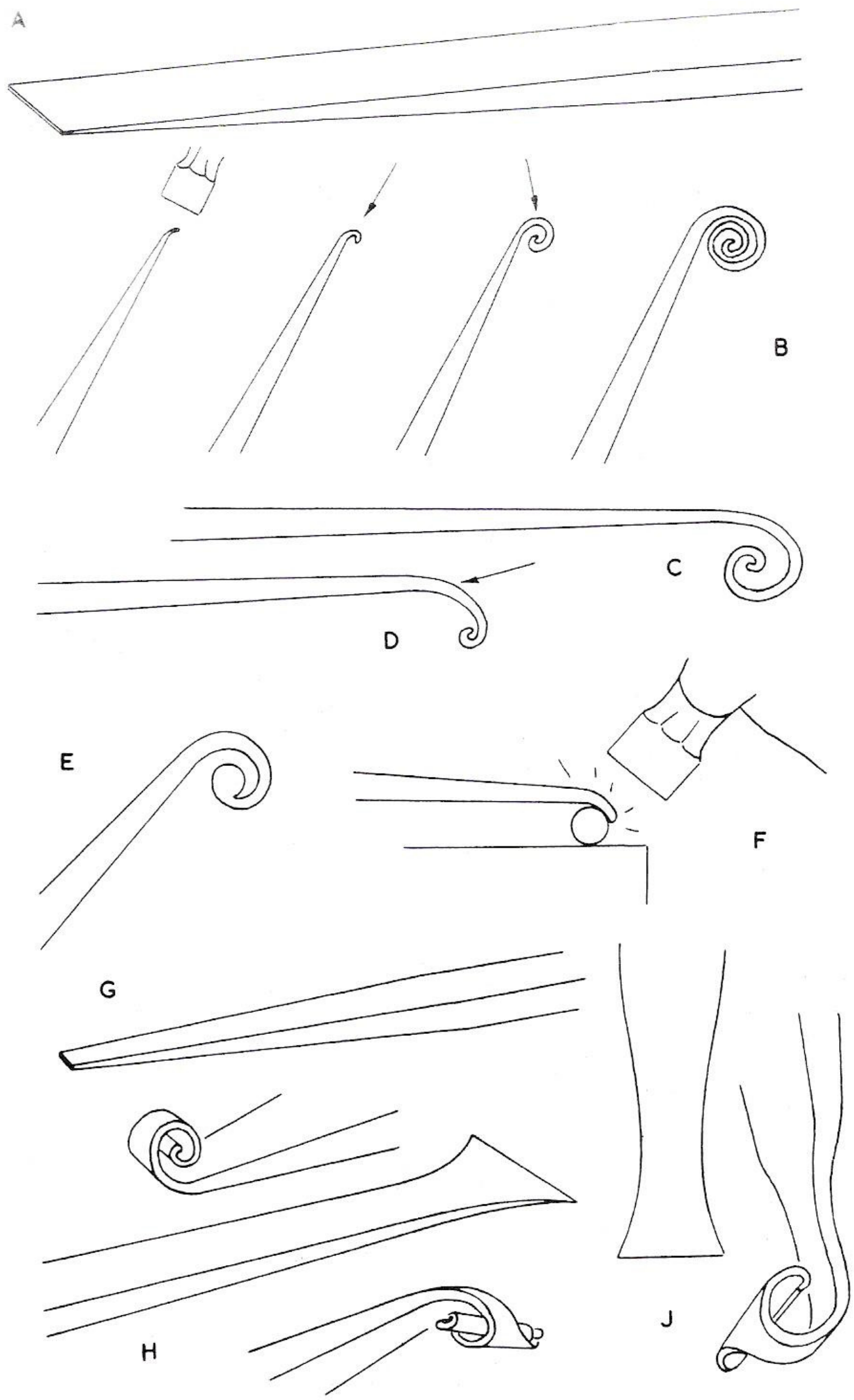


Figure 12 – Scrolls

In decorative ironwork, tapered ends are decorated by scrolls.

(A) Draw down and taper

(B) Curl

(C, D) Styles of curls

(E) Snub end

(F) Heat and hammer

(G) The end is drawn down

(H) Flair the end

(J) Narrow neck and roll

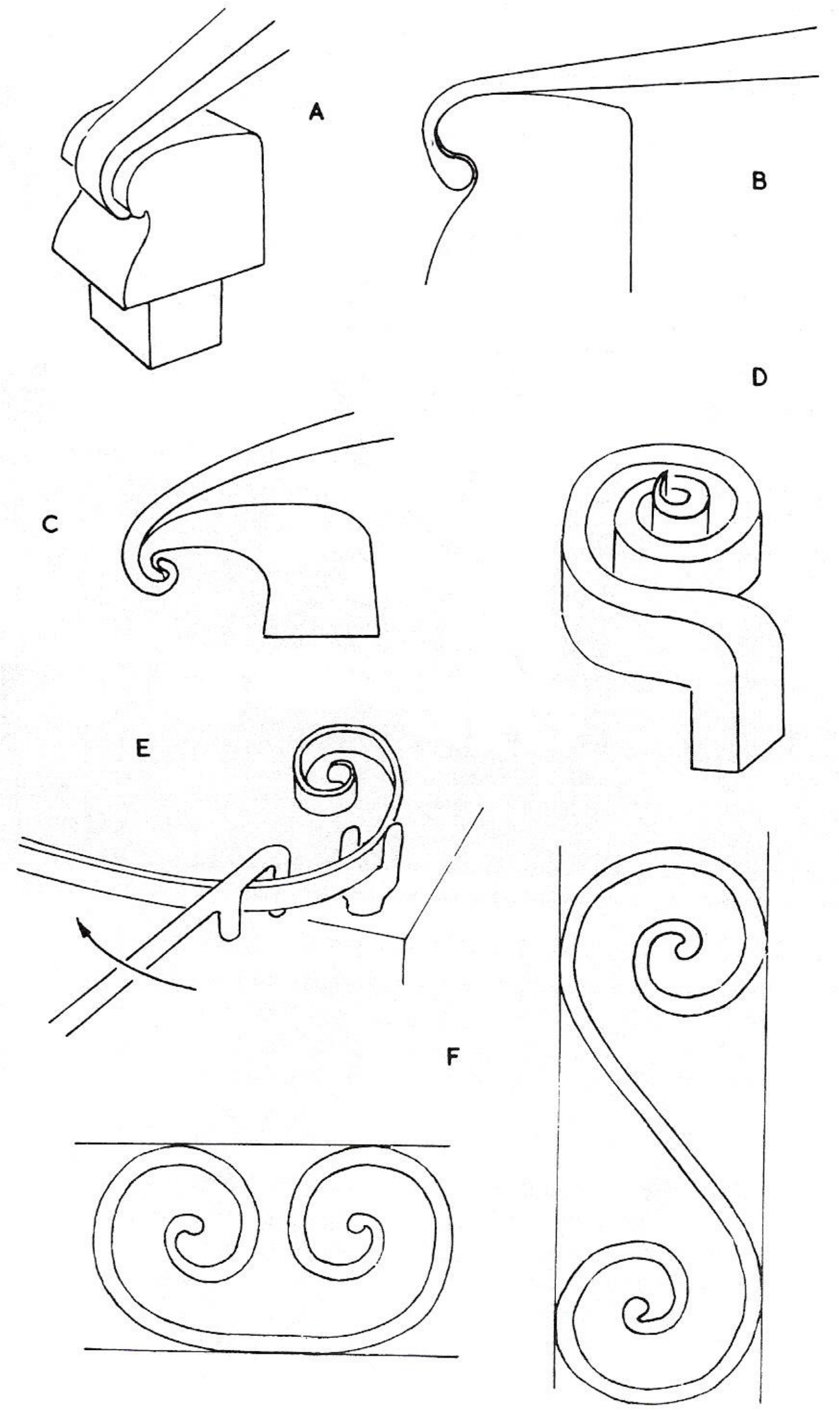


Figure 13 - Smith's Tools

Tools the smith can make help in shaping scrolls to exact sizes.

(A) Form a curve
(B) Snub end
(C) Scroll starter
(D) Scroll iron
(E) Lever curves while in a vise
(F) Matched scrolls

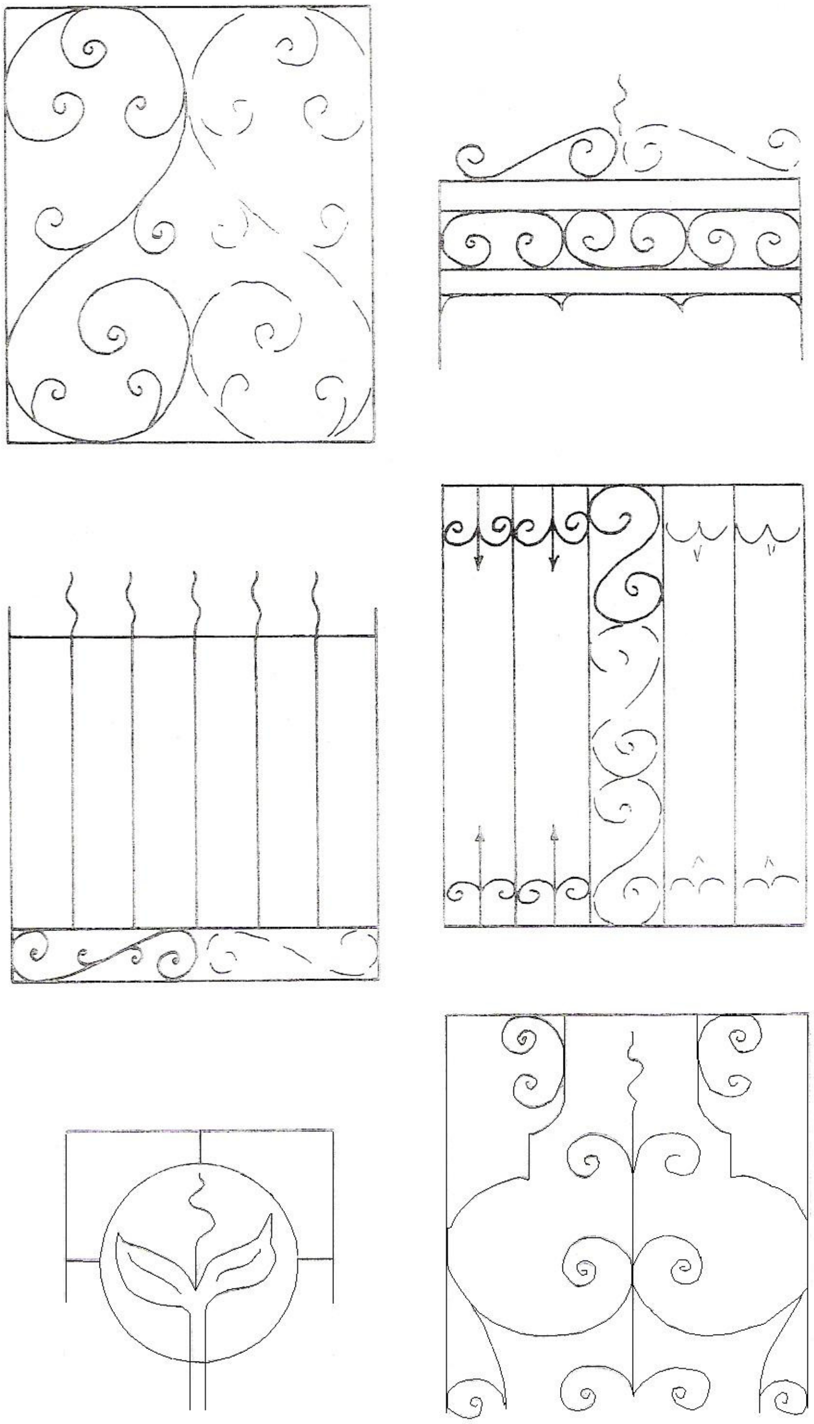


Figure 14 – Gate Scrolls

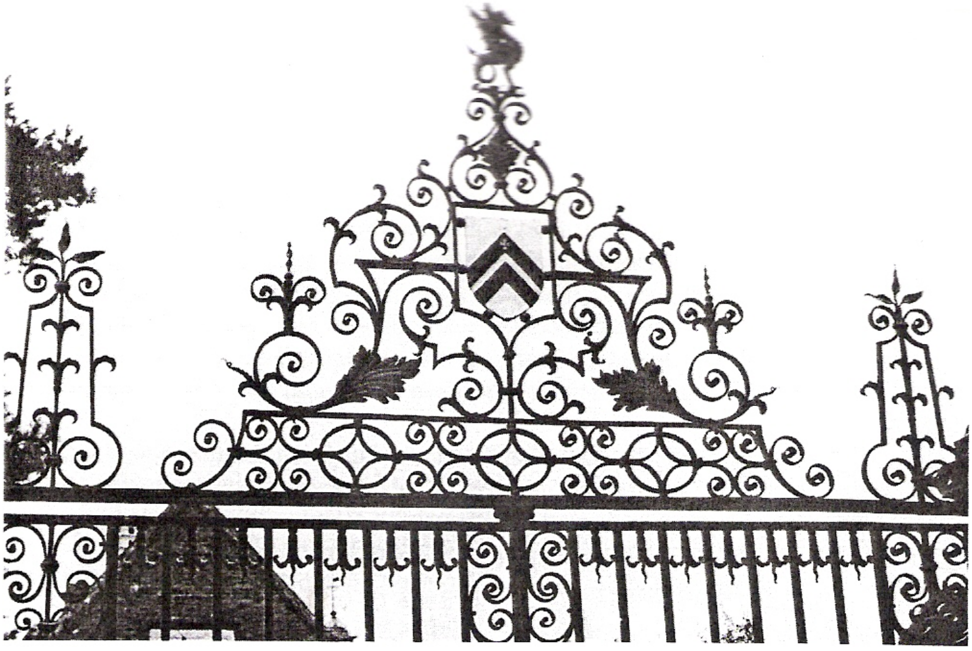


Figure 15 – Cast Leaves and Dragon

This gate top uses cast leaves and dragon, along with a painted shield, to enhance the many forged parts that make up the whole design.

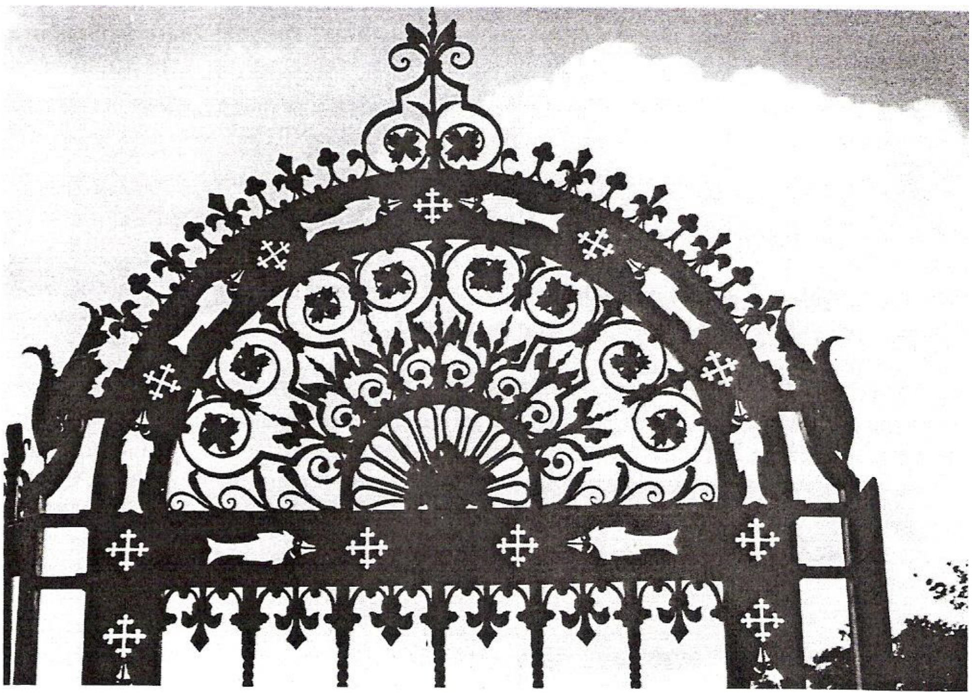


Figure 16 - Pierced Sheet Metal Decorations

Besides cast leaves added to the forged parts, this gate top also has pierced sheet metal decorations.

Wall Hooks and Brackets

Wall hooks are readily available as mass-produced metal and plastic articles, but there is a character about individually produced versions. A smith can easily make a variety of hooks.

A basic hook starts as a flat bar. One end is drawn out to make the hook. The hook is then curved and the top is rounded. An alternative method is to start the other way with round bar, which is flattened. To enhance the appearance, additional work can be done on the back and the hook.

The rectangular outline of the back can be broken up by hammering over the edge and the surface. The end can be split and curled outward. This will have a functional advantage in spreading the points of attachment to the wall. A simple curve to the hook can be improved by giving it a swan's neck shape.

If the tip is left thick and then upset, before the hook is curved, it can be given a round knob. Leave hammer marks showing. For ease in slipping a coat loop over the end, make the knob more oval, with the smaller curve outward.

Another way of dealing with the tip is to draw it down finely and curl it.

If it would be better for the tip to be wider to prevent things from coming off, flatten and curl the end. Some old wall hooks have heads on the end. This is not easy to do, but a knob can be converted to an animal's head by careful hammering and use of punches and files. A double hook can be made with different heads on the ends.

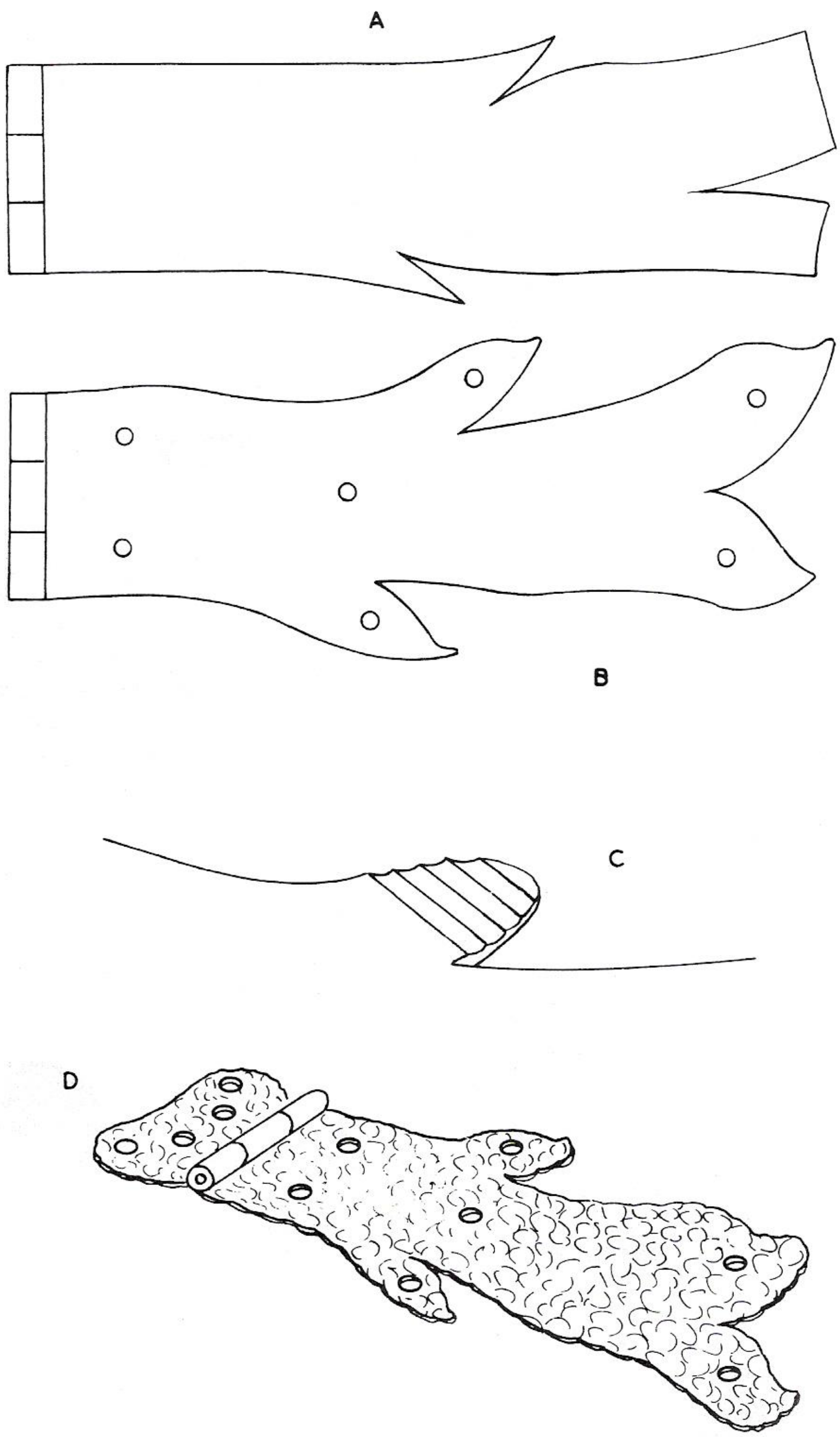


Figure 17 - Large Hinges

Large hinges can be decorated by splitting (A, B) and spreading edges (C, D).

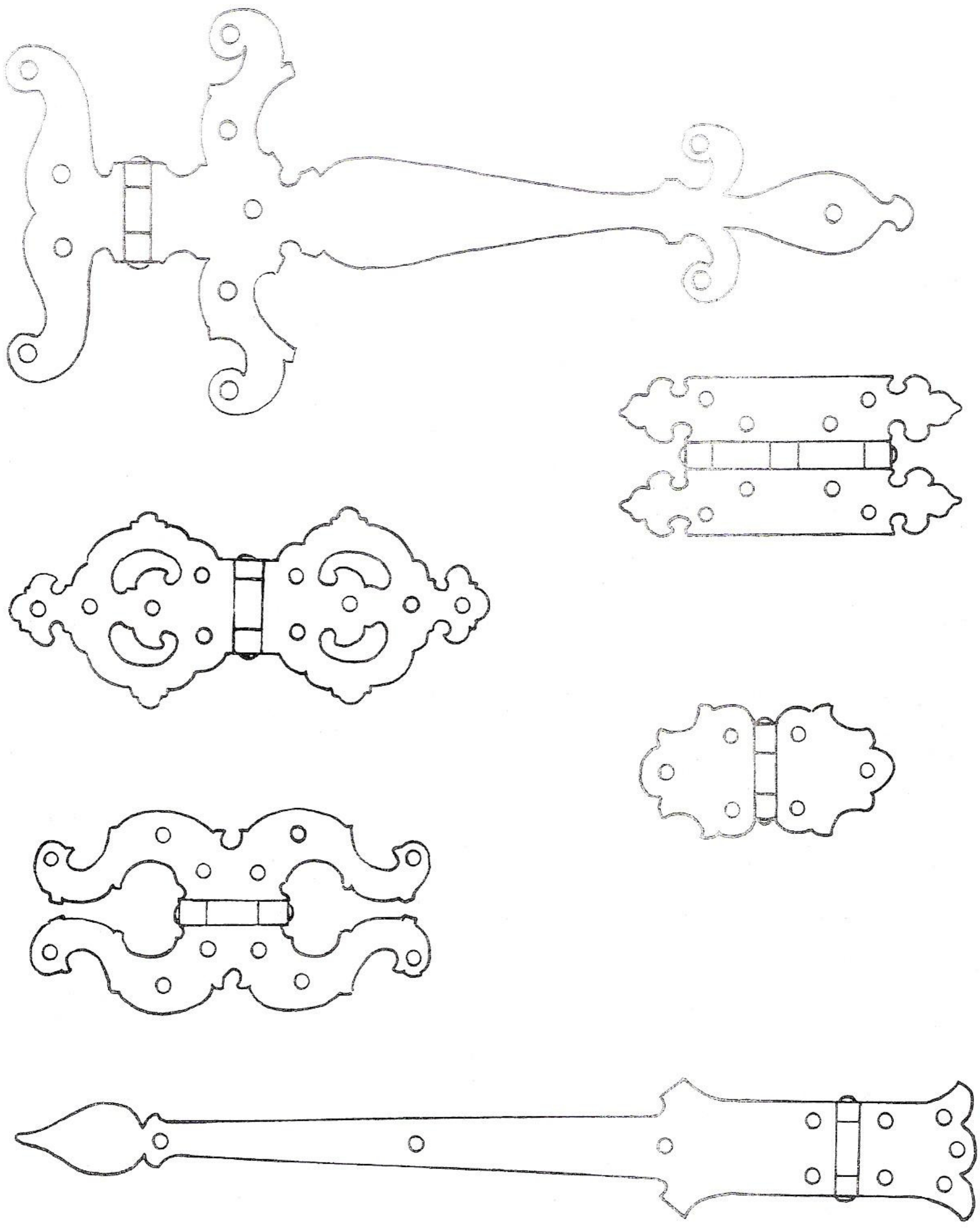


Figure 18 - Jacobean Hinges

Hinges can be cut to elaborate lines – as in these Jacobean hinges.

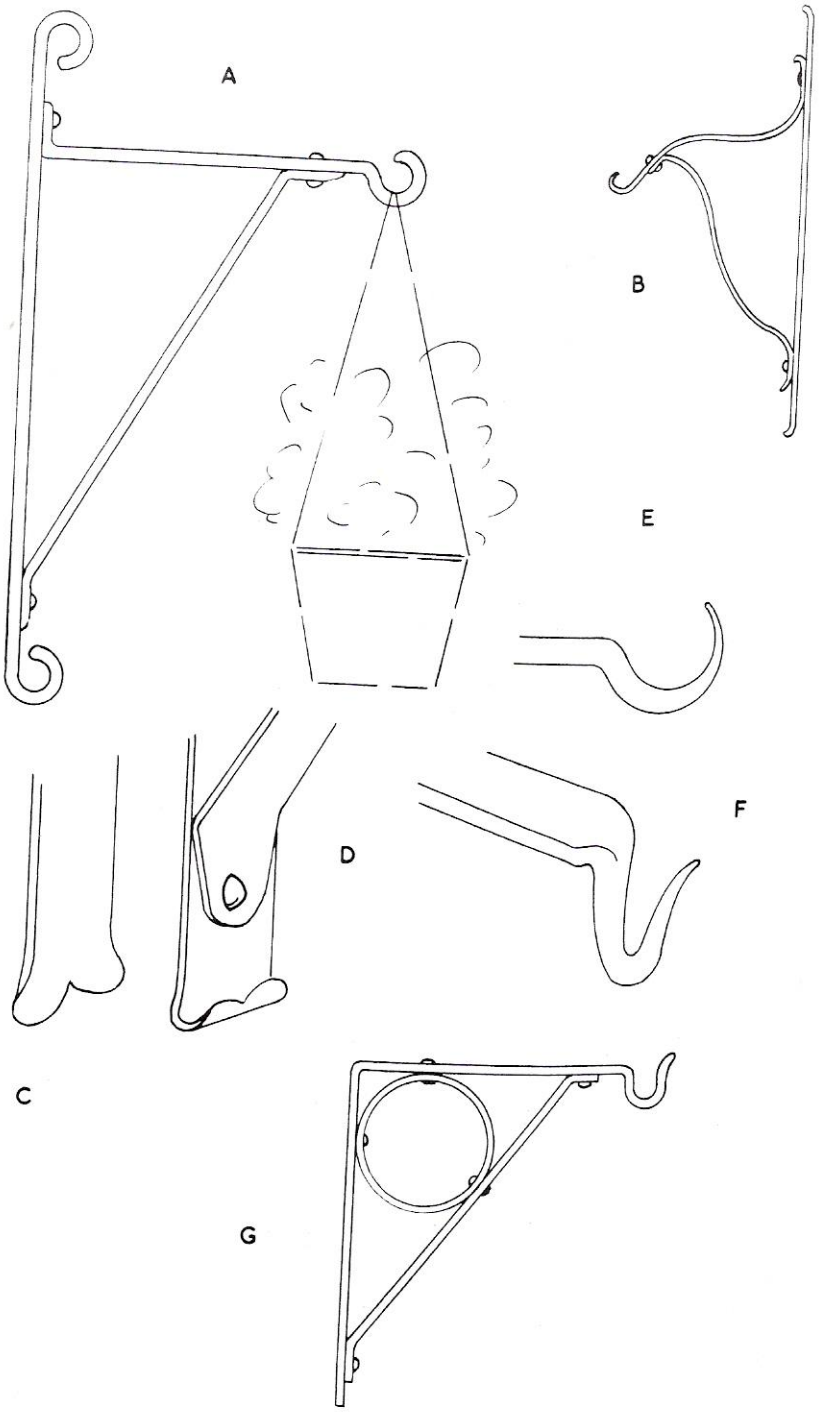


Figure 19 – Brackets

Brackets for other purposes can be made like shelf brackets.

(A) Bracket for hanging a basket

(B) Use curves

(C) The back strip is split

(D) Rivet ends

(E) Hook

(F) Deeper hook

(G) Decorative circle

The Effect of Forging on the Properties of Metals

The rolling and drawing processes to which metal bars are themselves forming processes and effect the ‘lay’ of the grain in the bar as shown in Figure 24.

Figure 24(a) shows a cast bar with its random grain or crystal structure. Figure 24(b) shows a rolled or drawn bar with its grain directed along the length of the bar.

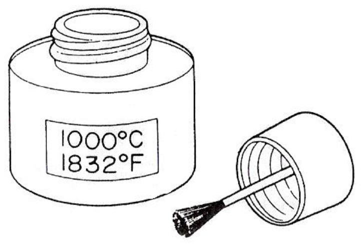
Metal	Procedure
Aluminium	The approximate annealing temperature (350°C to 400°C) is indicated by one of the following methods: 1. Heat the metal slowly until when stroked with a thin stick of white wood, a dark brown ('charred') stain appears on the metal's surface. 2. Lightly smear the metal's surface with machine oil and heat until the oil smokes and is burnt away. 3. Heat until the surface of the metal is stained black when rubbed with a piece of soap. After heating the metal may be cooled slowly or quenched; the cooling rate is immaterial.
Brass	The cold-working brasses commonly used in sheet-metal work should not be heated above dull red (500ºC). Those containing up to 63% copper must be cooled slowly while brasses containing more than 70% copper can be quenched in water.
Copper	The metal is heated between blood red (650ºC) and cherry red (750ºC) and may be quenched or slowly cooled. Quenching removes the black oxide scale formed on the metal's surface during heating. This scale, which remains when the metal is slowly cooled, can be removed by 'pickling'.
Mild Steel	Heat to a bright red (approximately 900°C) and allow to cool as slowly as possible. Dry clean sand or ashes can be used to retard the cooling rate.

Zinc	Zinc must not be worked when completely cold because normal room temperature is below that at which this metal will remain in an annealed condition. Before folding or severe forming operations can be carried out, the metal should be heated to approximately 100°C, and this temperature should be maintained during forming. As soon as drops of water begin to hiss and rapidly evaporate when allowed to fall on the warm surface, the zinc is ready for forming.
The general practice is to uniformly heat the metal to be annealed with a gas flame.	

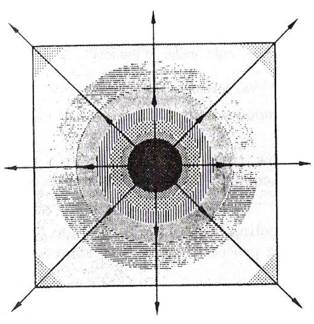
Table 1 - Typical Workshop Methods of Annealing

The component shown in Figure 25(a) may be machined from the bar or 'upset' forged. The differences in the lay of the grain between machining and forging the component are shown in Figure 25(b) and (c).

If the component shown in Figure 25 was to be used for a gear blank, this difference in grain orientation would be very important. Figure 25(a) shows that the grain of the machined blank is parallel to the teeth of the gear, causing planes of weakness. The teeth would break off relatively easily. Figure 26(b) shows that the grain of the forged blank would be at right angles to the teeth of the gear. This produces strong teeth. Remember that grain in metal behaves like grain in wood; metal breaks more easily along the grain than across the grain.



Heat sensitive paint is used for general heat-treating or heat-processing, particularly on areas not readily accessible for temperature indicating crayons; ideal for smooth and polished surfaces, such as plastics and polished metal surfaces.



Heat-sensitive paint will change in shade or colour to indicate a change in temperature.

The diagram shows the effect of temperature distribution on a metal plate which has been coated with a special heat-sensitive paint, and then locally heated at the centre with a welding torch.

The heat is conducted out towards the edges, and the ‘rings of colour’ change clearly indicating the great variation in temperatures.

The forging process also breaks up and refines the crystal structure of the metal. The finer the crystals become, the tougher and stronger the metal becomes. The temperature at which the metal is forged is important. Figure 28 gives the upper and lower temperatures for forging various metals.

1. If the upper temperature is exceeded, burning and grain growth will occur.

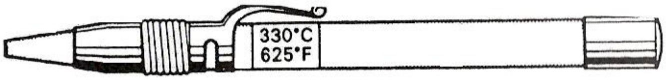


Figure 20 - Temperature Indicating Crayon

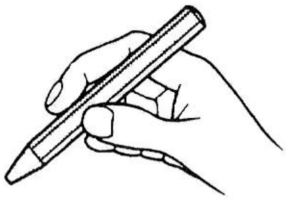


Figure 21 – (1) Select Crayon for the Required Temperature

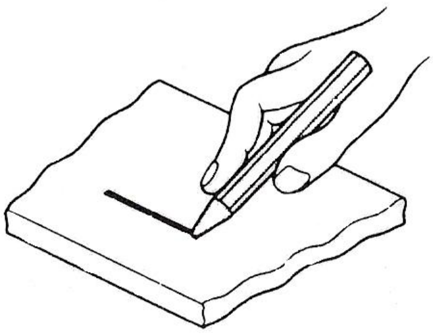


Figure 22 - (2) Mark the Workpiece

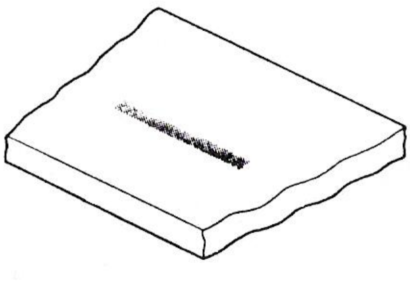


Figure 23 - (3) Crayon Mark Melts When Specified Temperature is Reached

This is a simple but accurate method of determining temperatures in soldering, brazing, welding and heat treating. It can be used for many other heat-dependent operations, for example when forming 'thermo-plastics'.

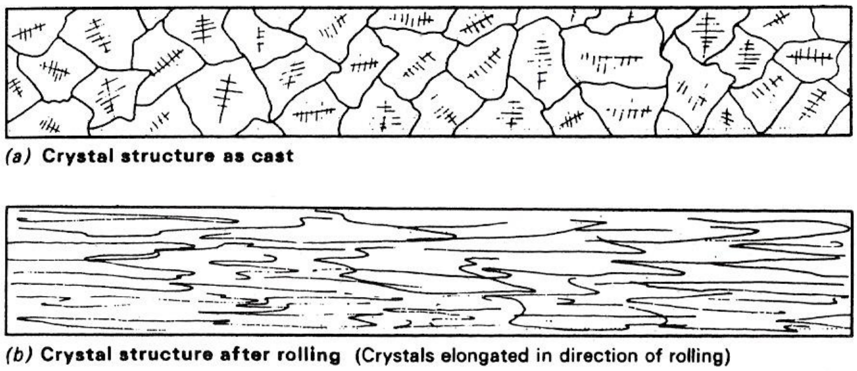


Figure 24 - Grain Orientation

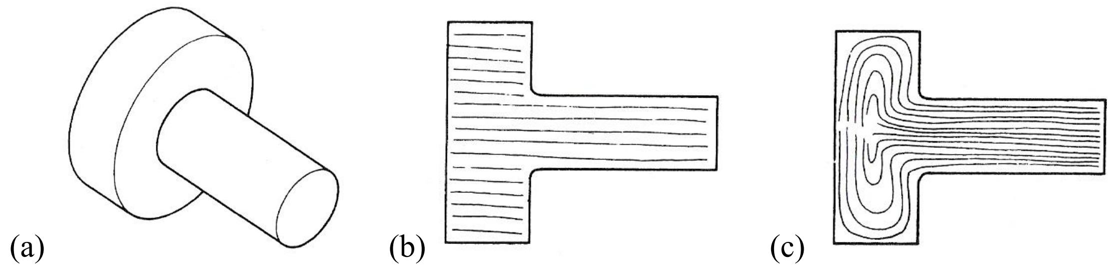


Figure 25 - Comparison of Machining and Forging

(a) This component can be produced by machining from the bar or by forging. The effect on grain structure is shown in (b) and (c).

(b) Grain structure when machined from the bar.

(c) Grain structure when upset forged.

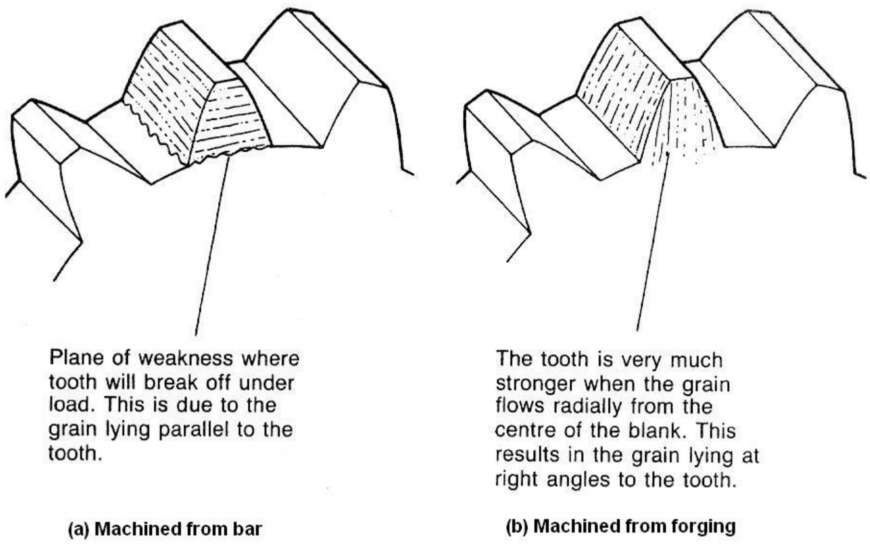


Figure 26 - Effect of Grain Flow on Component Strength

2. If forging is continued below the lower temperature, work hardening will occur and the component may crack and become weakened.

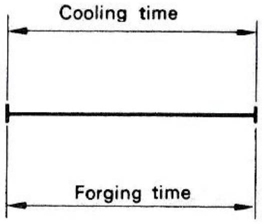
It is important to relate the cooling time of the component to the time taken to complete the forging process. Figure 27 shows some examples of what can happen.

In Figure 27(a) the forging process and the cooling cycle take the same time. This is ideal as no grain growth occurs after forging has finished, neither has any work hardening and cracking occurred.

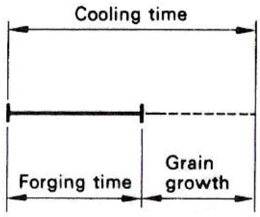
In Figure 27(b) the forging time is very much shorter than the cooling time. Grain growth occurs after forging has finished and this reduces the strength of the component. To prevent this, either the component is not heated to the maximum forging temperature, or the forging is subjected to grain refinement heat treatment processes after it has cooled down.

In Figure 27(c) the forging time is longer than the cooling time and reheating is necessary. As in Figure 27(b) the maximum forging temperature of the reheat must be carefully judged, or grain refinement after cooling must be carried out.

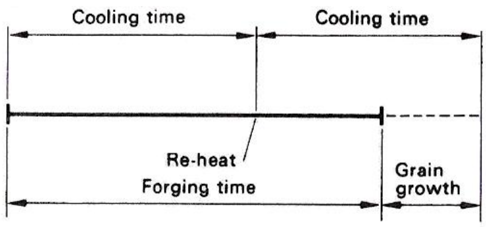
The skill of the blacksmith lies in suiting the forging temperature to the process. However, in production forging, or where large components are being forged, grain refinement is carried out after cooling. Although an added expense, it is cheaper than scrapping a large and costly component or a large quantity of mass-produced components.



(a) Ideal situation
Cooling and forging times are identical.



(b) Forging time less than cooling time:
(i) Low carbon steel components-quench after forging.
(ii) Medium and high carbon steel components - heat treat to refine grain after cooling.
(iii) Medium and high carbon steel components – reduce cooling time to forging time by not bringing component up to full heat.



(c) Where re-heating is necessary
The conditions discussed in (b) apply to the second cooling/forging cycle.

Figure 27 - The Forging Cycle

The advantages of the forging process may be summarised as:

1. *Economy in the use of raw materials.*
   Less time is used and less swarf is produced when machining from a forging, than when machining from the solid.
2. *Increased strength* compared with the same component made from a casting or machined from the solid.

Forging Copper Alloys and Aluminium Alloys

Forging has little or no effect on commercially-pure copper and aluminium.

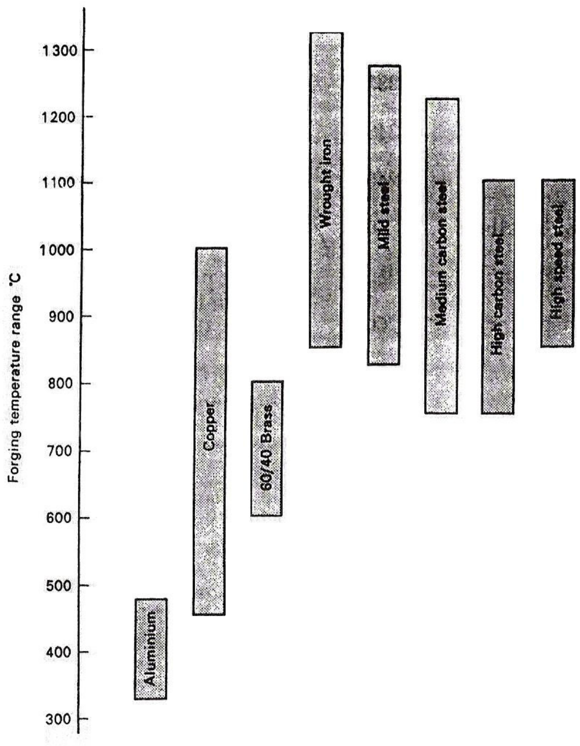


Figure 28 - Forging Temperatures

1. Neither of these metals is susceptible to quench hardening, so the rate of cooling is unimportant.
2. Since forging is always carried out above the temperature of re-crystallisation both these metals will be in the annealed condition when they have cooled down.

   However, most high duty copper and aluminium alloys are heat treatable. Therefore, their properties will be affected by:
   (a) the forging temperature
   (b) the time they are held at that temperature
   (c) the rate of cooling.

   Aluminium alloys are normally forged between 340°C and 450°C.
   Copper alloys are normally forged between 750°C and 810°C. Cooling should be as quick as possible. Alternatively, the properties of the alloy can be modified by solution heat treatment after forging. If in doubt always consult the alloy manufacturer's technical literature before forging or heat treating these materials. Aluminium alloys must be rapidly heated to forging temperature. Slow heating would result in a coarse grain structure. If the alloys are overheated they will be susceptible to cracking during the forging operation. Fairly light hammer blow must be used because heavy blows result in surface cracks with cannot be welded up by subsequent forging (as in the case with ferrous metals).

Casting

An alternative to forging and fabricating metal is to melt it and run it into a mold. When metal is extracted from ore it is run into molds, then the blocks are further worked during manufacture to form the bars and sheets we use. If sufficient heat is available, most metals and alloys can be melted again and poured into molds of any shape. It is the amount of heat necessary that limits the choice of metals that can be cast in a small shop.

If some decorative ironwork is examined, much of it will be found to be a combination of forged and cast iron. Castings are used where an animal or human face has to be included, or where there are floral representations too complicated for forging. The gate to a medieval castle might have the coat of arms of the owner as a centrepiece cast to shape. Many small decorations, such as a cast-iron flower finial come at the end of a forged bar. Cast iron of this type is rather brittle, but used for decoration without fine detail, this does not matter. In the industrial production of cast iron and steel, there are techniques that overcome any tendency to brittleness and other faults. Many steel tools start as castings. Casting is also valuable where weight is important. Anything bulky, and therefore heavy, is almost certainly cast.

Unfortunately, the heat required to melt iron and steel is more than can be achieved in a blacksmith's shop. The end of a bar might be heated enough to melt away, but what is required is enough heat to melt a quantity of metal in a container to a state where it is fully liquid and can be poured. The heat limit restricts the casting done in a small shop to those metals and alloys with low melting points.

Lead is the metal in general use with the lowest melting point. This is a good choice for practice castings. It does not cast with very sharp angles, but if it is alloyed with antimony it becomes printers' type metal and will cast sharply. Proportions are four parts lead to one part antimony. Old printing type could be used. Aluminium has about twice the melting temperature of lead, but that heat should be possible using a blacksmith's hearth. Some fires might only melt brass. Zinc is not readily available, but if it can be obtained, it can be alloyed with lead and antimony to make a good casting metal that is within the heat range of a smith's shop. A suitable proportion is 14 parts lead, five parts zinc and one part antimony. Typical melting points are shown in Table 2.

Metal	Degree Fahrenheit	Degrees Celsius
Lead	621	327
Zinc	787	419
Antimony	1166	630
Aluminium	1214	660
Brass	1650	900
Iron	2768	1520

Table 2 - Melting Points

Most metals and alloys shrink as they cool. This will have to be allowed for in making a casting. A shrinkage of about ⅛ inch per foot is probable. An alloy containing antimony keeps its size or expands slightly on cooling.

Lead and type metal can be melted in an iron container. A ladle could be used for small quantities, but a handled iron pot with a spout is needed for larger quantities. Metals that require a higher temperature should only be melted in a crucible, which is made of fireclay or plumbago. Special long tongs with jaws are used to embrace the crucible. Obviously, molten metal has to be handled with great care, and early experience is best gained with lead or its alloys melted in a ladle. If a metal runs where it should not, smother it with sand. Never pour water on it.

Metal can be melted repeatedly. Old castings can be melted to make new things.

Cutting or breaking into small pieces will speed melting. Once there is some molten metal, anything solid lowered into it will soon melt. Impurities will rise to the surface and this dross should be skimmed off with a small ladle before pouring. When metal is poured, do not break the flow.

Casting is done in a mold; sometimes the whole process is described as molding.

For metal casting, the mold is usually made of sand. Sea sand or builders' sand is not really suitable, although you can experiment with whatever sand is available. The best material is sold as foundry sand or green sand, which has the right proportions of clay and silica to give a good bond combined with ventilation. It is used slightly damp. Having it too wet could be dangerous when the moisture comes into contact with the hot metal. A mixture with five percent water is about right. To test for the right amount of moisture, squeeze a handful of sand tightly. It should keep the shape of your hand when released. If much sand adheres to your hand, it is too wet.

Single Mold

For most casting, the mold has to be in two parts. But some simple things that have a flat part pointing upward can be made in a single mold. An example is a lead block to be used as a weight (Figure 29A). In a simple example, the hole is not cast, but is drilled or punched afterward.

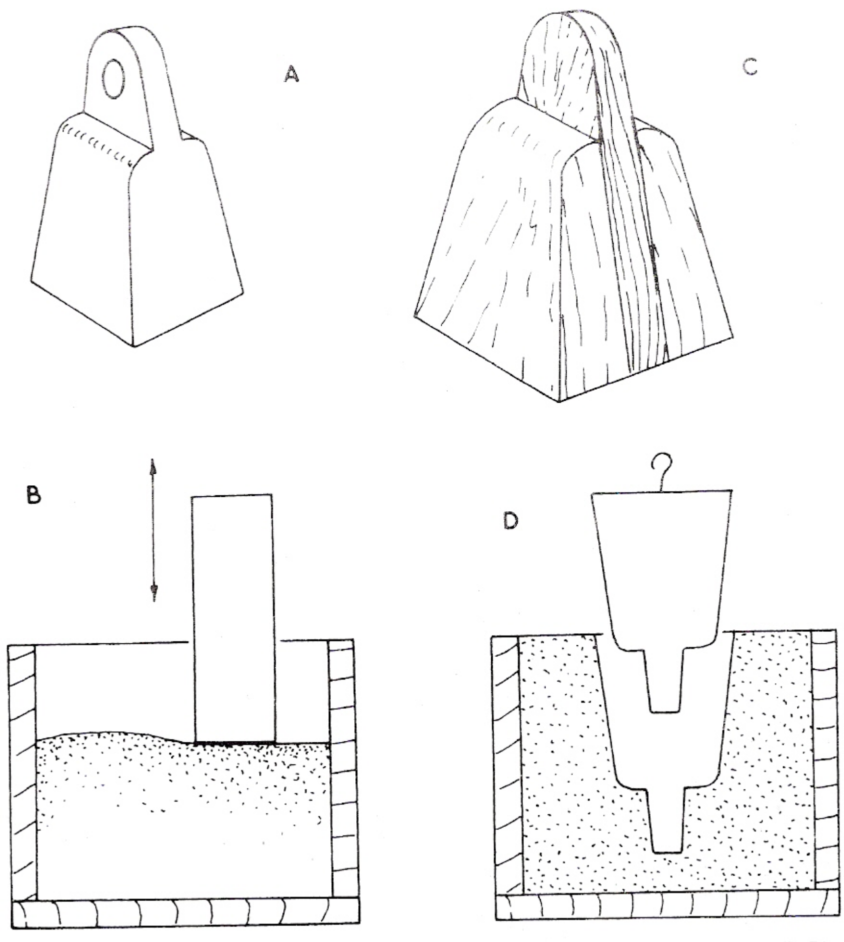


Figure 29 - Using a Lead Block as a Weight

In Figure 29 a weight (A) can be cast from a wooden mold (C) in a wooden box (B, D).

Use any wooden box that is big enough to hold enough sand and stout enough not to burst when the sand is rammed tight. Put sand in the box and ram it down a little at a time with a flat-ended piece of wood (Figure 29B) or even the handle of a hammer.

Make a wooden pattern of the weight. It must be tapered so that it can be withdrawn from the sand. This applies to the narrow part for the hole as well as the main body. It could be cut from solid wood or built up (Figure 29C). If a lathe is available, a round pattern can be turned. Finish the surface smooth. It does not matter what kind of wood is used. For general patternmaking in industry, pine and mahogany are used. For this weight, the wood can be used as it is. When a pattern is to be used many times, it is usual to seal its surface with shellac or varnish.

Scoop out some sand from the middle of the box and press the pattern in. It helps to put a screw eye in its base so it can be withdrawn (Figure 29D). Ram the sand tight around the pattern and level its top. When you are certain it is closely packed, withdraw the pattern and examine the mold. Pour lead in until it is level and let it cool. Then remove some sand so that you can lift it out. Punch or drill the hole. File or hammer the bottom level.

This is the basic method that can be used for the simplest castings. For most casting, the mold is made in two parts even when one surface of the finished work is to be flat.

Flat-Faced Castings

Molding is done in flasks, which are boxes open top and bottom, and arranged to fit against each other. In production work, the flasks are cast iron. However, small work can be done in wooden flasks. The lower one is called a drag and the other is the cope or top part.

Wooden boxes can be made in identical sizes (Figure 30A). Pieces across the end act as handles and provide positions for locating dowels that stand up from the drag and engage easily in holes in the top part (Figure 30B). So that the parts cannot be reversed in relation to each other, have the dowels off-center so that they will not match the other way. It will help to have grooves on the insides of the box to provide a key to grip the sand (Figure 30C). Sizes will depend on the work to be done, but the wood should be thick enough to remain stiff and the corner joints should be strong.

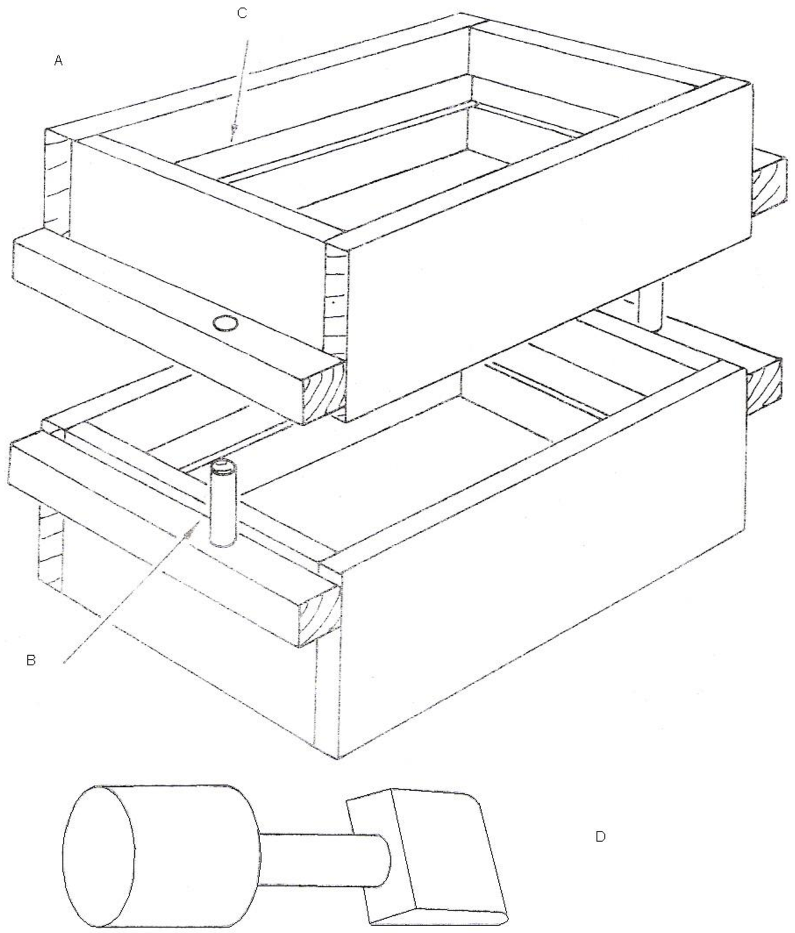


Figure 30 - Wooden Flask for Casting

A wooden flask for casting can be made as two open boxes.

(A) Identical size boxes

(B) Dowels

(C) Grooves

(D) A narrow tapered end

Although green sand is used in the flask, there has to be another sand to sprinkle between the meeting surfaces to prevent them from bonding together. The parting sand is used dry and can be bought as such, but brick dust can also be used. It is sprinkled through a fine sieve or riddle (mesh about $\frac{1}{16}$ inch) over the sand in the drag, and sometimes on the pattern before it is put in.

A rammer is a sort of straight-ended mallet that can be wood or iron. A narrow tapered end will get into smaller spaces (Figure 30D). Have a trowel available for dealing with sand.

If the object to be made has a flat face and the rest of the shape can be tapered to withdraw from the sand, the whole shape can be arranged in one half of the flask. The weight previously described could be made in this way; a stepped pedestal would be another example. Make a pattern and include a slight taper to all edges. Surfaces can be flat because they do not affect withdrawal (Figure 31A).

Put the pattern on a flat board and have the drag face downward around it. Sprinkle facing sand through the sieve on the board and pattern. Put in green sand with the trowel and press it down at intervals with the rammer (Figure 31B). Make sure the whole box is filled. See that sand is forced into the corners. Fill to overflowing and then scrape the surface level with a straight-edged piece of wood.

Lift and turn the drag over. Put the top part in place, and sprinkle facing sand in.

Stand a tapered rod slightly to one side of the pattern so that the metal can be poured in (Figure 31C). This is called a gate stick and can be wood or metal. It could be round, a tapered square, or octagonal. Fill the top part with sand, ramming it tight in the same way as the drag and then scrape its top level.

Ease out the gate stick, tapping it gently at the side to loosen it. The top of the hole left can be made into a funnel shape for ease in pouring metal.

Lift away the top part and put it aside, face up. Cut a small channel from the gate stick position to the pattern, to serve as a runner for the molten metal when it is poured. A piece of sheet metal folded into a deep scoop or gouge will cut the runner (Figure 31D).

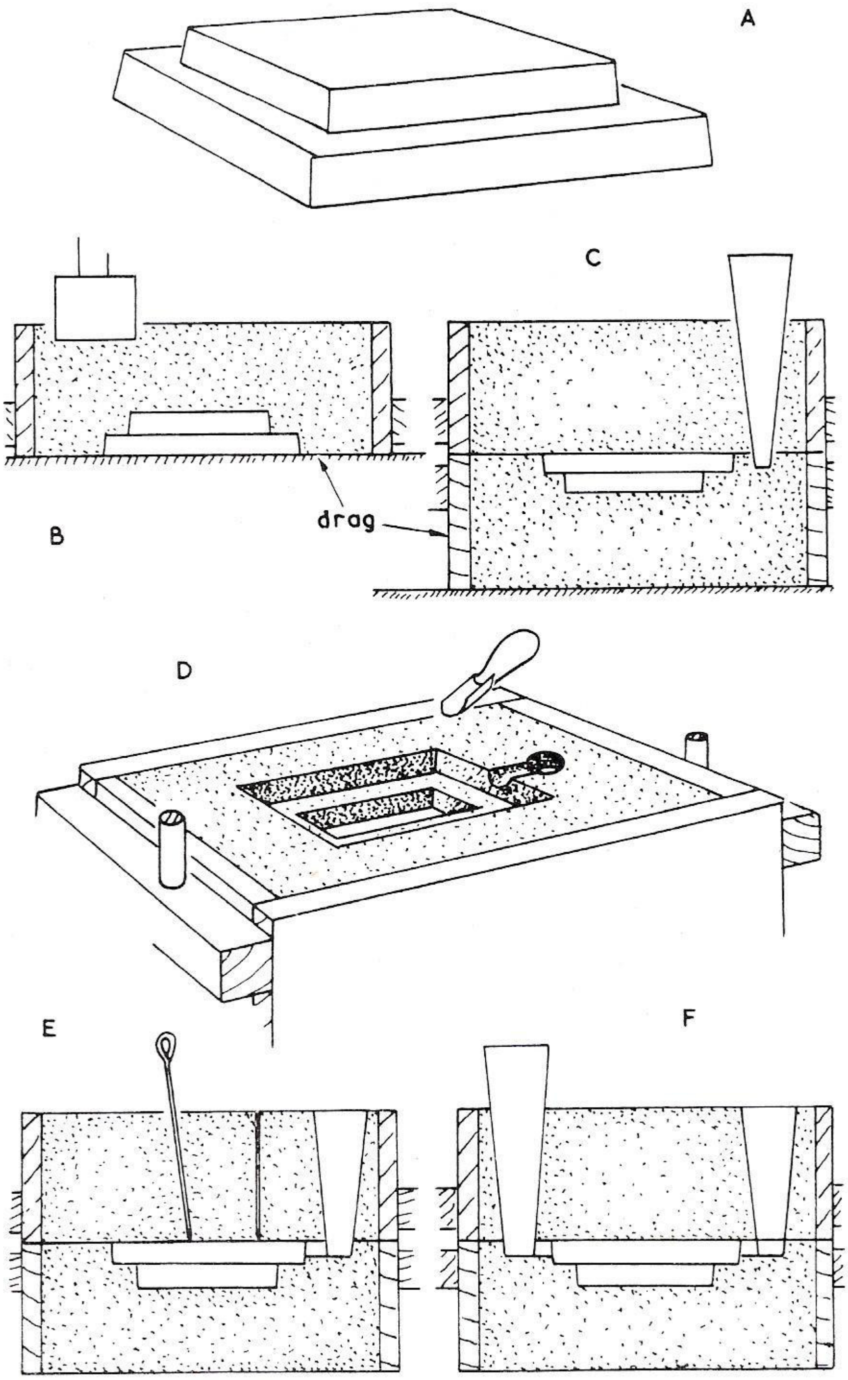


Figure 31 - Flat Pattern

A flat pattern (A) goes into one part and is covered with and in the other part (B). Then the sand is cut to allow pouring molten metal (C). A deep scoop (D) will cut the metal. A pointed wire (E) allows air to escape or you can use a riser (F).

To get the pattern out, enter the point of a screw in it, so that it can be used as a handle. There will almost certainly be a few flaws in the maid where sand has fallen or broken away. Bellows can be used to blow away loose sand. If repairs have to be made, there are molders' tools that are used like small trowels for pressing sand into place. They can be made by a smith and are bars with opposite ends formed into small trowel shapes (Figure 32).

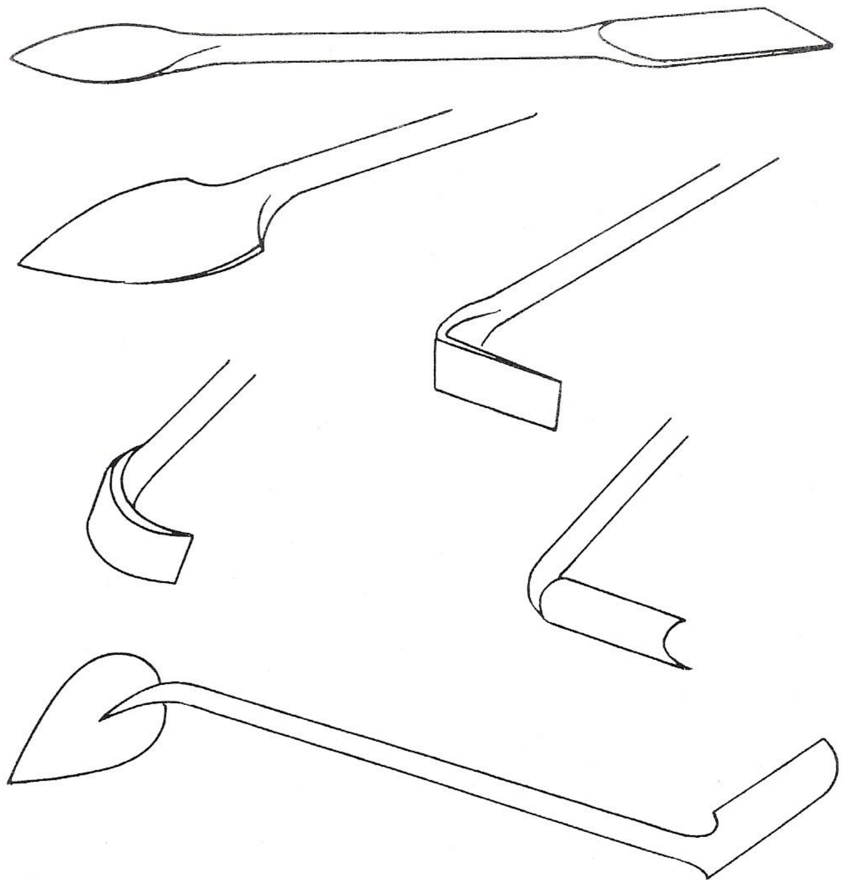


Figure 32 - Small Steel Hand Tools are used to correct a Mold

If the work is small, all that has to be done now is to put the parts of the flask back together and pour the metal. There will be enough ventilation in the sand to carry the air away, but the pouring metal will put pressure on the whole mold, so the top part should be weighted or attached to the drag to prevent it from lifting. For a clean casting, the inside of the mold can be dusted with graphite.

If the work is larger, it is advisable to provide some escape for air as the metal is poured in. This can be done while the pattern is still in place by pushing in a pointed wire pricker at several places until it is felt pressing against the pattern (Figure 31E). For a very large casting, it might be better to provide a hole called a riser. A riser is really a repeat of the gate stick hole at the side remote from it (Figure 31F). Excess metal that has run off that way or into ventilating holes will have to be cut off after the casting is removed.

Symmetrical Castings

Many things that have to be cast could not be made in one half of the flask because it would be impossible to withdraw the pattern. Many castings have a cylindrical form. The only way they can be cast is to have half in each part of the flask so that the curves are into the sand, which should not be disturbed when the pattern is removed.

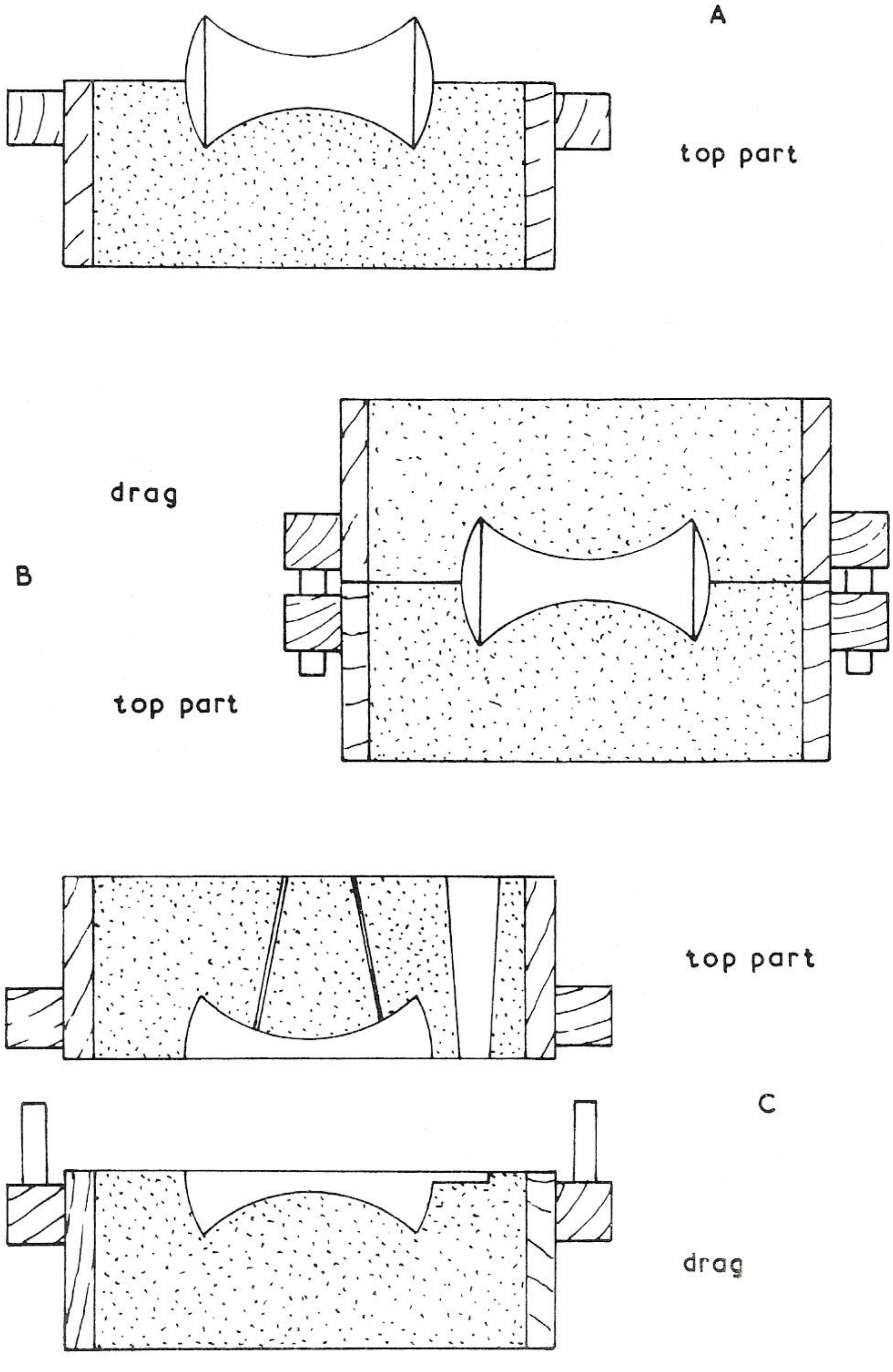


Figure 33 - A Symmetrical Item is Arranged in both Parts of a Flask

To get a tight pack of sand in each part when a solid symmetrical pattern is being used, preparation has to start with a temporary filling of the top part of the flask. Place the top part with the side that will be toward the drag upward, and fill it with sand. Pack it reasonably tightly and press the pattern halfway into it (Figure 33A). If it is a big pattern, cut out some of the sand first and finish the sand surface level.

Put the drag on and sprinkle on parting sand. Fill the drag and ram the sand tightly.

Scrape it level (Figure 33B). Turn over the flask to bring the drag underneath. Separate the boxes carefully to leave the pattern in the drag. Knock out the sand from the top part. Put it back on the drag, sprinkle in parting sand, and repack the top part tightly. Then scrape it level. Having this extra stage is necessary because the first filling of the upper part cannot be done tightly enough.

With both parts of the flask properly packed, use the gate stick and make ventilating holes if they are needed. Then separate the parts and remove the pattern (Figure 33C). Cut a runner and clean up the maid if necessary. Dust with graphite. Put the parts back together and pour the metal.

Cored Castings

Many castings have to be made with holes through them. Sometimes holes are drilled, but it is helpful to cast the hole when the metal is poured. For many purposes, that is all that is needed. For more precision, the cast hole can be opened to size. To make a hole, there has to be a core arranged in the mold so that the metal flows around it and the core can be removed from the casting after it has set.

Suppose a cylindrical casting is required with a hole through that will be machined to make a bearing (Figure 34A). A core must be made longer than the final length of the casting so that it can be supported in the molded sand. This is built up in a core box, which is a two-part mold, into which the sand mixture can be packed (Figure 34B). Make it from wood, with half the diameter gouged from each part. Use dowels or other pegs to keep the two parts correctly located in relation to each other (Figure 34C).

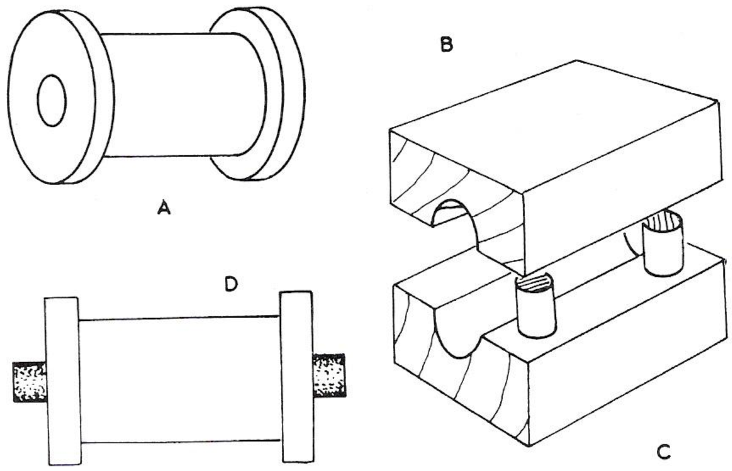


Figure 34 - Hollow Casting

A hollow casting requires a core that is formed in a core box.

(A) Cylindrical casting

(B) Two-part mold

(C) Dowels are used to position the parts

(D) Core prints are used to make patterns

The core will go into the sand so it is supported outside the main hollows left by the pattern. To allow for this, the pattern is given core prints (Figure 34D) that are the diameter of the core and that extend far enough to make the recesses in the sand. In pattern making, it is usual to stain the core prints so that they are a different color from the main pattern, to indicate that they are not part of the final shape. Of course, the overall length across the core prints should be the same as the length of the core.

Blacksmithing Traditions

When Stone Age man first succeeded in separating metal from ore and making something from it, blacksmithing was born. The first metals were impure copper with traces of other metals; these have become known to us as bronze. Men of the Bronze Age made tools and weapons from this comparatively soft metal, and these were much more successful and convenient than their crude stone implements. But it was not until they discovered how to obtain iron from ore that tools and weapons of adequate strength could be made. In the Iron Age man learned to use heat to fashion iron and the foundations of smithing that were laid then have not changed in principle today.

The first evidence of smithing by hammering iron was found in Egypt and dated 1350 BC. It is a dagger, believed to have been made by a Hittite craftsman. It is fairly certain that the Hittites invented tempering and forging, then they kept their ironwork techniques secret. The Hittite empire was overthrown about 1200 BC, and a large number of migrants spread throughout what are now Europe and the Middle East, taking their ironworking skills with them first to Greece and the Balkans. This early Iron Age was from about 800 to 500 BC. Then ironworking spread further west in Europe and to Britain, during what is often called the Late Iron Age.

If was combining iron with wood that made possible the cultivation and clearing of land and the use of wheeled vehicles. Iron also made better weapons for hunting and warfare. Considering this, the smith was an important member of every community. By later Biblical times the smith was using an air-blown fire to heat his iron, and working in ways not much different from smiths today.

The smith finds a place in classical mythology - Roman and Greek, as well as Aztec and Phoenician. In Roman mythology Vulcan, son of Jupiter, is credited with being the founder of smithing. According to the stories, he made the axle for the chariot of the sun and the gates of dawn. He forged the thunderbolts his father used. In Norse mythology, Loki gave power to Thor as a smith. Quetzalcoatl of the Aztecs brought skill in ironworking and other crafts to the people. A similar story goes with Tuba-Cain of the Phoenicians.

In many mythologies, the smith is ugly or evil. Such has been the treatment in some countries of smiths in more recent times, possibly because they worked with fire in semi-darkness - things that were associated with the devil in the minds of superstitious people. Smiths were important in medieval times with the need for armour and weapons, but in some places they were almost outcasts. This did not apply everywhere; there are records of kings working with their favourite armourers. It must have made sense to take part in the production of something that had to be relied on to preserve life. Some smiths were artists in metal and proof of this is seen in surviving gates and other ornamental wrought-iron work (Figure 35).

You might have noticed that the name of the craft has been given as smith and not blacksmith. The family name Smith indicates how many people were once concerned with the craft of smithing. Smiths in earlier times did all kinds of metalworking, as it was needed. Later developments brought specialists in working lead and other metals. In particular, the worker in lead became known as a whitesmith, so the worker in iron became known as a *blacksmith*. That is the usual name today for anyone who uses heat and hammer to shape iron or steel.

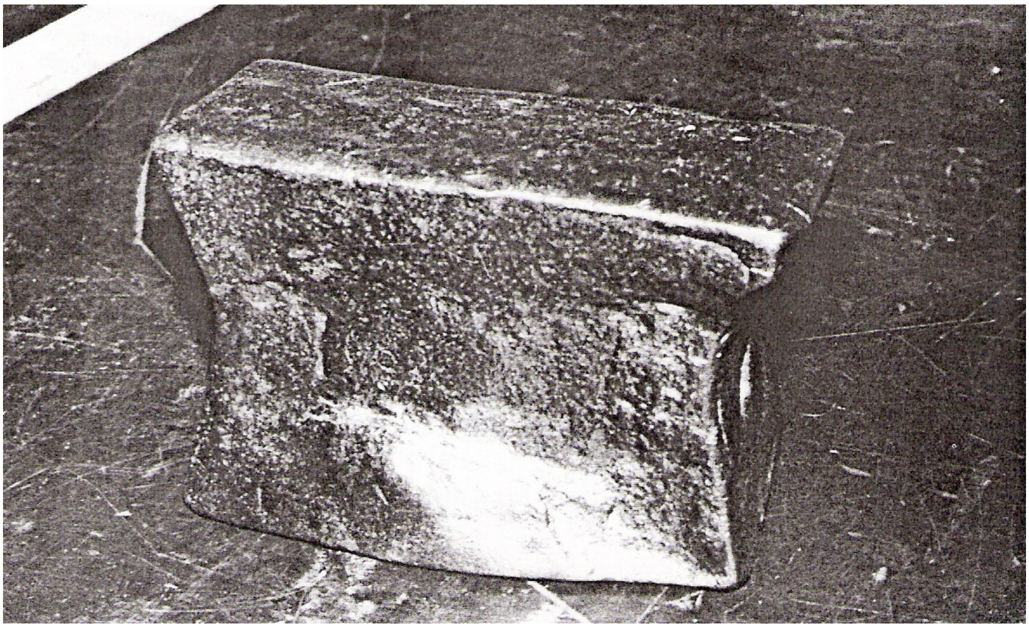


Figure 35 - Medieval Anvil

This medieval anvil without horn or holes was probably used by an armourer.

To many people the name includes the craftsman responsible for the making and fitting of horseshoes. Strictly speaking, that craftsman is a *farrier*, although most smiths in the days of the great use of horse transport were also farriers. However, there was and there still is a distinction, and not every farrier or blacksmith could do the other man's job. There were other specialist smiths. A chain smith forged links in a chain. A nail smith (often a woman) did nothing but make nails. Today a blacksmith, whether professional or amateur, can expect to do all kinds of smithing and may need knowledge of horseshoeing as well.

In the days when most countries depended on a rural economy, there was a blacksmith's shop wherever there was a cluster of dwellings. His customers were the farmers and workers who lived nearby. He probably farmed a piece of land himself. A comparable life was led by the village carpenter. Quite often they had adjoining shops and certain implements needed on the land or some piece of equipment to be used in a house would be a combined effort. Wagons and carts required both skills. In later years the wheelwright became a specialist craftsman, leaving the carpenter to other woodworking. There are many places in Europe where it is still possible to see the stone base (probably an old millstone) on which the blacksmith and the wheelwright worked together to assemble a wheel and draw the parts together with its iron tire.

There would also have always been blacksmiths working in towns, and some of them would have specialised in making gates and other wrought-iron work. There would have been armourers who made weapons as well as armour. Smiths were also employed on the great estates attached to feudal castles, and worked with other craftsmen on ecclesiastical buildings and furnishings.

Like most other craftsmen, blacksmiths were their own masters and independent, depending on payment from customers. Work might be done by barter for a share in the crop at harvest time or in return for some service rendered. These methods continued until the Industrial Revolution, not two centuries ago, when factory production began to replace the work of individual craftsmen. This affected blacksmiths in the same way as others who had enjoyed the independence of their craft. The need for individual smiths diminished, but many smiths were able to find places for their skills in industry. Many became factory workers.

The use of steam and other power introduced processes and techniques that would have been beyond the smith and his helpers, who had only their muscles for power. Gas and electric welding made possible the fabrication of parts that would have previously involved lengthy and laborious work at fire and anvil. Mass production had taken over and people had no use for the one-off products from the smith or other craftsman that cost more than the factory-made products.

Of course, horses were still being used at this time, and there was still need for rural smiths. The use of working horses did not really decline rapidly until the end of World War I. By then, the internal combustion engine in vehicles - particularly tractors - took the place of horses. Those smiths who wanted to maintain their independence had to broaden their scope. Some learned to maintain motor vehicles or they became agricultural engineers, with blacksmithing only a part of their activities.

Blacksmithing as a craft is no longer in great demand for its practical applications.

Much of what a smith did for purely utilitarian purposes in the past can now be done more effectively by other means. However, there is still the need for a one-off product that would be better made by smithing, and there is still a place for the artist blacksmiths who can create wrought-iron work in a way that mass production cannot. There is no longer a need for a blacksmith in every community, but there is still a place for those who treat blacksmithing as a means of using craft skill in the same way that others may hammer a copper bowl, make furniture or pottery, carve wood, or weave a basket. Whether they do this for profit or just for the love of a craft, they will get a tremendous satisfaction out of forming iron, and carrying on one of the oldest crafts.

Design

Throughout most of history the majority of blacksmiths were concerned with producing implements for use. Design work was often directed toward making the thing as suitable as possible for its intended purpose; appearance was of secondary importance.

Sword hilts and similar items were decorated with cuts and punchings. Other products often obtained any artistic effect from their layout and proportions. The art of the blacksmith is geared more to large items than small ones, and the artistic ability of individual blacksmiths can be seen in railings, gates, screens, and ecclesiastical decorations. On a smaller scale were locks and hinges, where iron was wrought to shape and decorated with cuts and stamping.

There are still in existence in Europe elaborately scrolled hinges with rather rudimentary surface decoration made with punches. Twisting strip metal into scrolls is a feature of much early wrought-iron work.

Blacksmiths concerned with decorative ironwork were influenced by the Gothic style in architecture. In the 15th century tracery intended for stone was repeated in iron, sometimes more effectively. This continued into the 16th century, when much cast iron came into use.

Up to this stage, design was the concern of the individual. There are some surviving examples of excellent work, but not of any sort of design standard. This was also true in woodworking, particularly furniture making. Craftsmen might have copied good ideas from each other, but designs were comparatively local. The printing press altered this. Chippendale and other great furniture designers and makers published pattern books and other furniture makers were able to produce chairs, tables, and many other things to these designs.

Almost the same thing happened to decorative blacksmithing. A Frenchman named Jean Tijou was called to England to work under architect Sir Christopher Wren on the ironwork for the royal palace at Hampton Court, alongside the River Thames to the west of London. He was an outstanding designer of ironwork and a very skilled blacksmith, with techniques that were mostly new to English craftsmen. He was at work on the palace ironwork in 1690 and he remained in England to publish designs in 1693. These were used by blacksmiths all over the country, and spread via immigrants to America. Much of his work was rather elaborate and flamboyant. English smiths modified his style to give a more restrained effect. However, Tijou can be credited with having raised wrought-iron work to classical perfection. His influence can still be seen today.

Introduction to Blacksmithing

One of the longest established crafts known to civilized man has held its place of importance through all the changes of thousands of years, while civilizations have come, grown, and gone, and others have taken their place. The skills of the man who could work iron and steel were always needed, and the blacksmith always held an important place among his fellow men. The methods have changed little. Very early smiths mastered the principles and these still hold good today. Improvements are in detail. A smith described in the Holy Bible would be able to comprehend what was happening in a twentieth-century smith's shop, while a modern smith, provided only with the tools of 2,000 years ago, would know what to do with them and be able to achieve creditable results.

After thousands of years with little change, a good deal of change has come to blacksmithing in the last 100 years or so, due to the Industrial Revolution. When the automobile replaced the horse, a smith was no longer essential to the community.

So where does that leave us? There are still blacksmiths able to earn a living primarily from smithing, but most have to broaden their scope to embrace metalwork that was not previously considered their work. There are still apprentices to blacksmithing. There are still manufacturers of the necessary equipment, although a smith is in the fortunate position of being able to make most of his own tools. There is still a demand for wrought iron work that shows the mark of individuality and does not obviously come from a factory where hundreds of similar pieces have been made. Above all, there is still a place for men or women determined to express themselves through craftsmanship.

Many people looking for a craft turn to wood, but not everyone wants to work wood or is capable of becoming a competent carpenter, wood turner, or carver. Much work in metal requires a considerable investment in equipment, but blacksmithing as described in this book need not be expensive. A small portable forge and an anvil of modest size (not necessarily new) are the essentials, then a few tools lead the way to making more tools. Much material can come from scrap sources. What other people throw away can be recycled by a smith into things of use or beauty or both.

Working on the anvil is a mixture of physical effort and artistic application. There is always a lot of satisfaction to be obtained from physical effort properly directed. Blacksmithing also offers this advantage: If it does not come out right the first time, it can usually go back into the fire for another attempt.

Blacksmithing can be an adjunct to another craft. A mastery of hot iron allows the making of many things that can be used with other metal or wood constructions. The smith's metalwork will be a fitting companion to the projects of other branches of craftwork.

Self Assessment

Questions on Background Notes – Module 1.Unit 9

1. Metals Expand and Contract, list two factors for this to happen.

2. List the three types of Hardness Tests on material. Briefly explain one.

3. In Heat and Temperature Measurements of material, what is a Tempilstick?

4. Briefly explain Conduction/ Convection/ Radiation in the transmission of heat.

5. What is Annealing?

6. Briefly explain the Tempering Process.

Answers to Questions 1-6. Module 1.Unit 9

1.

a. The amount the temperature changes.

b. The type of material.

2.

a. The Brinell.

b. The Vickers.

c. The Rockwell.

(See Hardness Tests: Module1. Unit 8. P12.)

3.

A crayon that is simply stroked on the job and melts at the stated temperature.

They range in calibrated steps from 30° → 1600°c.

4.

Conduction / Convection / Radiation.

5.

Annealing:
This Process makes a metal soft and workable and relieves internal stresses in material.

6.

When a metal has been hardened it sometimes becomes brittle.

This can be reduced by Tempering:

The part is cleaned to bare metal, this ensures easy recognition of colour changes when the metal is heated.

1. **Heat the metal, the first colour to appear is yellow and so on.**
2. **Quench the metal in water immediately when the correct colour is reached.**

(See Quenching Colours Chart: Module 1. Unit 8.P21.)

Bibliography

Books:

Basic Welding & Fabrication

W Kenyon

ISBN 0-582-00536-1

Practical Blacksmithing & Metalworking (2nd edition)

Percy W. Blandford

ISBN 0-8306-0394-8

ISBN 0-8306-2894-0

Fundamentals of Fabrication & Welding Engineering

F.J.M. Smith

ISBN 0-582-09799-1

Index