2. THE HF WELDING PROCESS

This section describes the HF welding process in simple terms. The fusing of the materials in the area of the weld is explained, followed by the methods used to *practically perform the weld.*

2.1 WHY USE HIGH FREQUENCY POWER ?

Plastic materials can be welded by applying heat externally, e.g. by using a tool similar to a domestic iron or a hot air gun. Generally, this form of welding is restricted to very thin materials, such as Polyolefins.

Bulky items, such as some tarpaulins which are too large to be accommodated in an HF welding machine, are sometimes welded by using a hot air gun. This type of *welding is difficult and can only be successfully carried out by experienced operators.*

Other types of plastic materials can be welded by direct heat alone, but the process is impractical. If direct heat alone is applied to PVC, it can degrade the outer surface, which may overheat before the inner surfaces are hot enough to weld together.

The High Frequency welding technique overcomes the problems associated with the application of direct heat alone, and enables plastic materials to be welded under controlled conditions.

By applying a controlled amount of High Frequency (HF) power, it is possible to heat the materials so that the zone of resulting higher temperatures includes the surfaces to be welded together. Heating the contact boundaries using this method forms a strong weld without damaging the outer surfaces of the materials.

High frequency welding depends on a process of converting electrical energy into heat energy within the workpieces to raise their temperatures enough to melt, and therefore fuse them.

Materials that do not conduct electricity such as air, oil, and PVC are sometimes called dielectrics. In HF Welding, the plastic dielectric materials to be welded are sandwiched between two conductors, called electrodes. When HF power is passed between these electrodes, an alternating electric field is generated through the dielectric materials. The switching electric field agitates the dielectric material's molecules causing it to heat up. The effect of heating is at a maximum at a point half way between the electrodes, at the junction of the two dielectric materials due to the heat-sink effect of the colder electrodes in contact with the outer surfaces.

Once the dielectric materials have fused, the HF power is switched off and the workpieces are allowed to cool.

The frequency used by most HF welding machines is 27.12MHz, this means the electric field is cycled 27.12 million times per second. As each cycle comprises a positive half cycle and a negative half cycle, the electric field is applied at twice the frequency, i.e. 54.24 million times per second.

2.2 PRACTICAL HF WELDING

In HF Welding, the lower electrode is usually a wide flat metal plate generally called a platen. A large welding machine may also be provided with a moving upper platen which carries tooling shaped to create the required weld pattern in the workpieces.

The upper platen is connected to the HF supply and moves up and down during the welding process enabling the tooling to be brought into contact with the workpieces. The force with which the upper platen presses against the workpieces can be applied by springs, weights or for 'heavy' welding by electric motor, compressed air or hydraulics.

The lower platen is connected to electrical earth, and is usually fixed in position. This platen must be strong enough to withstand the pressure applied by the upper platen.

2.3 BARRIER MATERIALS

A barrier, or buffer, material is a thin sheet of dielectric that is placed between the work material and the welding machine's lower platen. This can help the welding process in several ways, dependent on the properties of the barrier material. Any material used as a barrier must be able to be repeatedly used in the electric field without being affected.

Barrier material has two distinct purposes. Firstly it prevents the cutting edge of a tear-seal electrode touching the bottom platen and thereby causing an arc, and secondly, it provides a thermal barrier to prevent the bottom platen absorbing heat from the workpiece.

A barrier sheet will usually be between 0.15mm and 0.5mm in thickness, this is enough to decrease the heat flow, and increase the weld temperature thus allowing a larger area of weld to be made with a given amount of HF power. Too much thermal insulation will cause the workpiece to melt near to its outer surfaces, rather than at the interface of the two pieces.

The dielectric strength of a barrier material is measured in kilovolts per millimetre. This measurement gives an indication of the voltage which can be applied across the material before it breaks down and looses its insulation properties.

The most popular buffer materials are composite materials, e.g. waxed paper or varnished cotton. These flexible materials can be easily stored and cut.

Some examples of commonly used barrier materials are:

Elephantide — Supplied in various thicknesses and in rolls 48 inches (1219mm) wide. Also available with thin film Melinex laminated to its surface which gives a good shine on the reverse side of the weld line and the PVC has a tendency to stick lightly alone the weld lines.

Silicone Rubber — Flexible rubber sheeting, available in rolls of several thicknesses. Works up to 160ºC, non-stick, not affected by the HF frequencies used by welding machines. It is often used in car door panel production

Paxolin — Rigid sheeting of thermosetting resin impregnated paper, available in squares of different thicknesses and areas. Usually, the lighter the colour of the material, the better the quality. Its disadvantage is that it may split or crack when cut.

Melinex — This is a tough material that will resist the wear and tear from the cutting edges of any welding tools. It can also be used in combination with another material that provides additional electrical and thermal insulation.

2.4 SETTING MACHINE CONTROLS

The welding process is generally quite tolerant of machine settings, and satisfactory welds can be obtained even if one or more of the settings is not at its optimum value. The tolerance of the settings is dependent on the material being welded, PVC is relatively tolerant but other materials, for example medical films, are not. However, with optimum settings a satisfactory weld will be obtained over a wide range of conditions which may occur in a typical operating period. For example, the temperature of the upper platen will increase as work progresses and the workpiece material may vary in quality, even if from the same batch.

Settings for a specific job cannot necessarily be repeated at a later date. The composition and thickness of the workpiece material can vary, the components in the HF generator age and affect the level of the output power, and the mechanical components of the welding machine wear. Also the ambient temperature will vary from day to day and the incoming mains voltage may fluctuate. Many of these variables can be reduced or eliminated with sophisticated control systems.

Successful machine setting relies on experience and the careful monitoring of the completed work.

The following controls need to be correctly adjusted to obtain the optimum weld:

(a) Tool Pressure

(b) Press Stroke Adjustment

(c) Depth of Sink Control

(d) HF Power Output

(e) Welding Time

(f) Cooling Time

(g) Platen temperature

2.4.1 Pressure

This is the force applied to push the tooling into the workpiece. This adjustment is often overlooked, as the welding process is quite tolerant of force applied to the tools. Faster welds can be obtained by using greater pressures. Pressures as low as 1kg/cm^2 can be used to obtain a weld. For plain welding, a depth of sink control must be used.

The pressure applied should be enough to allow the tools to penetrate into the workpiece when hot. Care must be taken to avoid the use of excessive force, especially for cut-and-weld tools.

2.4.2 Press Stroke Adjustment

The press stroke is the vertical distance the upper platen or toolholder can travel, its adjustment depends mainly on the type of welding process. In a process where visibility of the workpieces is important, the upper platen must be allowed to travel clear *of the operator's line of sight. In automatic or high throughput processes, the amount* of travel must be limited to shorten the length of each process cycle.

2.4.3 Depth of Sink Control

The depth of sink control is most important when not using a tear seal tool. The sink control limits how far the tooling will sink into the PVC. Adjustment of this control will assist in obtaining the optimum weld strength.

2.4.4 HF Power Control

The power supplied from the HF generator depends upon, among other factors, the tuning of an electrical circuit. The tuning of that electrical circuit is usually achieved by means of a variable capacitor. Although this controls the power output, it is not possible to calibrate it directly because of the other variables. This is analogous to the accelerator in a car, it cannot be calibrated, because the speed depends on the road conditions, selected gear etc.

Great care should be taken to prevent too much power being used, as this will result in damage to the workpiece and tools. It is best to start with the adjuster set to zero, and steadily increase the power until the required power is achieved. It is better to use a little more time and less power, than the other way around.

When the material is heated, the electrodes will sink into the workpiece. This will cause the power drawn from the generator to increase. When the material reaches melting point, an electrical change occurs which causes the power to reduce. This falling back is often used to detect the completion of a weld.

2.4.5 Welding Time

This is the length of time that the HF power is applied to, and creates heat in the workpiece. A steady or falling power meter reading is an indication that the temperature within the workpiece is no longer increasing. The power should be terminated soon after this state is achieved.

This is very important, as over-heating can cause damage to the workpiece. Often, the effects of over-heating are not obvious, but they can be very serious. Not only the weld area is being heated, the rest of the workpiece is also being heated, which causes the material alongside the weld to weaken.

One way to check for over-heating is to inspect the area around the tool impression. If it "shines" or the finish has degraded, then the workpiece has probably been overheated.

2.4.6 Cooling Time

This is the length of time between the end of the welding time and the lifting of the welding tool from the workpiece. When the HF power has been shut off, the cooling process will be rapid, as long as the metallic tools are in contact with the workpiece. During the repetitive welding and cooling, the tools and surroundings become quite hot. Because of this, later pieces to be welded have a lesser rate of cooling into the warmer tools and worktable or loading tray. Therefore cooling time may have to be increased to compensate.

The pressure of the tools should be maintained until the temperature of the workpiece has fallen well below the fusion temperature.

Typically, the cooling time should be approximately 20% the length of the weld time.

2.4.7 Platen Temperature

Some welding machines, usually those used for welding thick materials or rigid PVC, have heated platens. By using a heated platen, the heat loss from the workpiece materials is reduced, enabling a larger area to be welded for a given HF power rating. Also, because the platen temperature is high relative to the ambient temperature and is thermostatically controlled, fluctuations in ambient temperature can be virtually ignored.

An uncontrolled platen temperature will rise as the production shift progresses due to the heating effect of the HF power being transmitted into the platen, and lead to modifications required to the power setting as the day progresses. A controlled platen temperature should give a static power setting and consistent weld throughout the production shift.

For rigid materials such as blister packaging applications, a heated platen is essential so that the tool 'beds down' into the material and closes any air gaps which could start an arc.

3. MACHINERY

3.1 GENERAL

There is a wide range of machinery used in the manufacture of plastic products. Generally, the machines are in the following groups:

(a) Preparation of materials for HF welding, e.g. cutters, slitters, panellers, guillotines etc.

(b) HF welding

(c) Assembly and finishing of the final product, e.g. tear sealing strippers, riveters, printers, press stud sewers etc.

Machines other than HF welding machines are outside of the scope of this handbook, but it should be remembered that many machines can be used in the manufacture of goods containing welded plastic components.

3.2 HF WELDING MACHINES

HF welding machine applications are very diverse. Machines can be used to produce a wide range of goods from small items such as key fobs to much larger items such as car components. To produce this wide range, many different types of HF welding machines exist.

It is not only the size of the components produced which affects the machine required to produce it, but also the type of component. For example a simple product may only require two workpieces to be welded. Other components will require assembling before welding, and finishing afterwards. These considerations affect the design of the machine.

3.3 MAJOR COMPONENTS

All HF welding machines incorporate four major basic components as follows:

(a) HF power generator.

(b) Press.

(c) Workpiece handling mechanism.

(d) Control system.

3.3.1 HF Power Generator

The HF power Generator produces high frequency electricity required to perform the welding process. In small machines, the generator is usually integrated into the casing of the machine, and in larger machines the generator is a 'standalone' piece of equipment located adjacent to the machine.

The frequency of the output is usually 27.12 MHz maintained to within ± 0.6%.

The maximum output power level varies from machine to machine, depending on the type of material to be welded, the thickness of the material and the area of the required weld. For any machine, the maximum power output, measured in Watts or kilowatts is known as the rating of the machine which is one of the most important items quoted in machine specifications. The ratings of machines vary from a few hundred Watts to tens of kilowatts.

The output power level can be adjusted to suit the conditions required for the weld. A visual indication of the output power is given by a panel meter, usually of the moving-coil type. By observing this meter, it is possible to monitor the progress of the weld.

The output stage of the generator incorporates thermionic valves. Although semiconductor devices could provide the required output power in the low power ranges, valves are far more robust, able to withstand the sometimes erratic loading caused by the welding process. Valves do gradually deteriorate with age and use, and need to be renewed after long periods of use (typically a few years).

3.3.2 Press

A press provides the means of pressing welding tools against work materials whilst applying HF power, plus the subsequent essential period of cooling time.

Pedal operated welding machines usually employ downstroking presses with versatile toolholding arrangements to press tools down on to the work material which is resting on a robust metal worktable, often called a platen.

Larger machines may provide an 'upper' platen to carry large tools which take advantage of the strength of that platen to prevent distortion when they are pressed onto the work.

There are two main types of press, a 'C' shaped press and a 'bridge' shaped press.

C type press - The side view of the press resembles the letter 'C' . This method of construction requires the use of relatively heavy cast components. Because the body of the press is located at the rear of the machine, accessibility to the work area between the platens is unobstructed. The RF power is fed to the upper electrode from the centre of the press. This type of press is used in machines from small foot-operated types to power presses capable of exerting several tonnes of force.

Bridge Press - The press is constructed using supports at both sides of the work area, with the upper platen operating from the 'span' between the supports. This method of construction provides a rigid and symmetrical press using relatively light weight components. The accessibility of this type of press is limited to the front and rear between the side supports. The RF power can be fed from both sides of the 'bridge' or centrally from the top to give a more even distribution of the RF field at the tooling.

3.3.3 Control System

The purpose of the control system is to ensure that the machine can be started, operated and stopped efficiently and safely. Control systems range from simple mechanical and electrical controls on small machines to full machine and process automation on large complex machines. Functions which can be controlled are:

a) Starting the machine in conjunction with any necessary 'safety' interlocks.

b) Monitoring and adjusting process parameters:

   (i) Stroke and pressure of the welding press.

   (ii) The HF power input to the workpiece which is the heating phase of the welding cycle.

   (iii) The timing of the heating and cooling phases.

   (iv) The operation of the handling system.

c) Stopping the machine in the event of an emergency or a potentially hazardous situation, e.g. an operator attempting to use the machine without a safety guard in place.

d) Monitoring the HF power to detect arcing and turning the generator off to limit the affects of arcing.

e) Protecting electric motors and other electrical components by tripping them out on the detection of an electrical overload.

Modern machines incorporate sophisticated control systems which use advanced software controlled devices such as microprocessors and programmable logic controllers (PLCs). These devices enable control functions to be implemented accurately with good repeatability.

3.3.4 Handling Mechanisms

The handling mechanism feeds the workpieces to the press, then positions them under the press for welding. Once welded, the workpieces are removed. There are several types of handling mechanism:

Manual On small machines, e.g. pedal operated, the workpieces are fed to the press, positioned for welding and removed by hand.

Linear A conveyor belt system feeds the workpiece materials to the presses. The conveyor belt stops to position the workpieces correctly for welding (this is known as 'indexing') then removes them from the press. When a linear indexing machine is correctly adjusted, the operator only needs to monitor the weld quality, ensure that there is a sufficient supply of workpiece materials, and remove the finished products.

Rotary A circular table rotates positioning workpieces correctly. This allows operators, at a number of workstations, to assemble the workpieces before welding and remove welded workpieces. The number of workstations of a rotary table depends on the complexity of the workpieces, and the number of finishing processes.

Rail When workpieces are too large to be accommodated in a fixed machine, e.g. tarpaulins, swimming pool liners etc., a rail handling mechanism is used. In this type of machine, the workpieces are held stationary and the welding press is moved along on a rail to perform repeated welds.

In addition to the handling mechanisms listed above, some machines, e.g. linear and rotary can be fitted with 'Placer' assemblies. These assemblies use pneumatically controlled suction cups to automatically pick up a component from a stack then place it on the work table ready for welding. Typical components that can be handled by Placers are grey board or PVC workpieces.

3.4 TYPES OF MACHINE

3.4.1 Foot Pedal

A typical Foot Pedal machine is shown Fig 3-1. The workpiece is placed on the lower platen which forms the work plate. The welding tool is brought into contact with the workpiece by pressing the foot pedal.

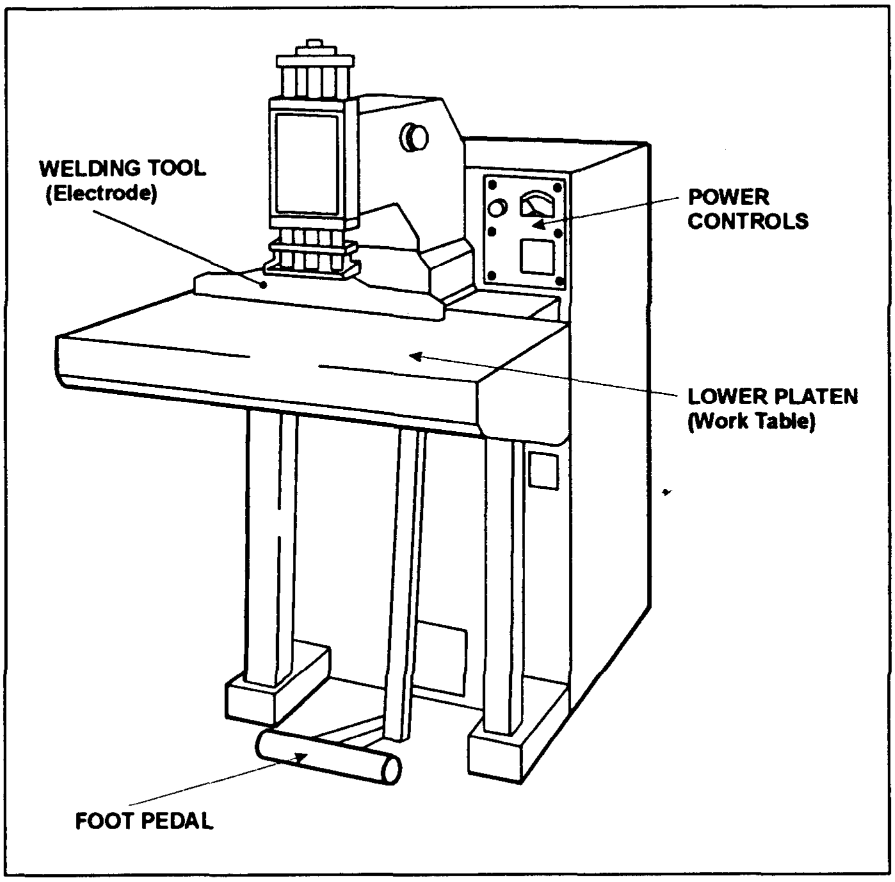

Fig 3-1 - Foot Pedal Welding Machine

3.4.2 Roll Fed Linear

A typical simple Roll Fed Linear machine is shown in Fig 3-2. The workpiece materials are fed from rolls mounted on the roll spindles. The conveyor belt carries the workpiece materials and barrier material through the machine, stopping to index each workpiece for welding. After welding, the batch of workpieces can be removed for finishing, e.g. stripping etc.

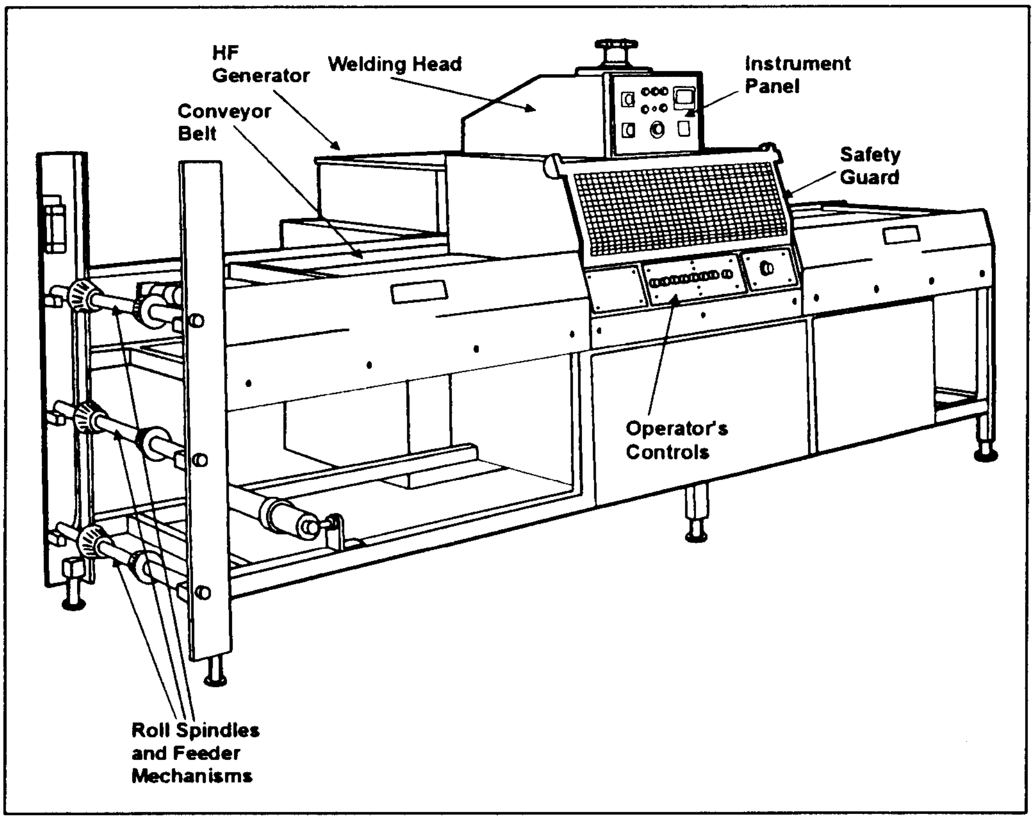

Fig 3-2 - Roll Fed Linear welding machine

Specialised versions of the roll fed linear machine can be far more complex. For example, a machine to produce stationery binders can perform the following operations:

(a) Feed the upper and lower workpiece materials from rolls, automatically adjusting the roll tension.

(b) Place the grey board between the two workpiece layers.

(c) Place a transparent PVC cover on top of the assembled workpieces.

(d) Weld the assembled components.

(e) Place a pocket on the spine of the binder, then weld it to the spine.

(f) Strip the welded binder from the surplus material.

(g) Stack the stripped binders onto a conveyor belt

This type of automated machine is expensive and setting it up for a production run takes typically one to two hours. Therefore for economic operation, the machine would only be used for production batches of 1000 or more binders.

3.4.3 Rotary Table

A Rotary Table machine is shown in Fig 3-3. This machine incorporates a circular table, with a number of work stations. Operators can either assemble, or strip, a workpiece at each work station. When a piece has been assembled, the whole table is rotated and the workpiece is welded. After welding the table is again rotated and the workpiece stripped.

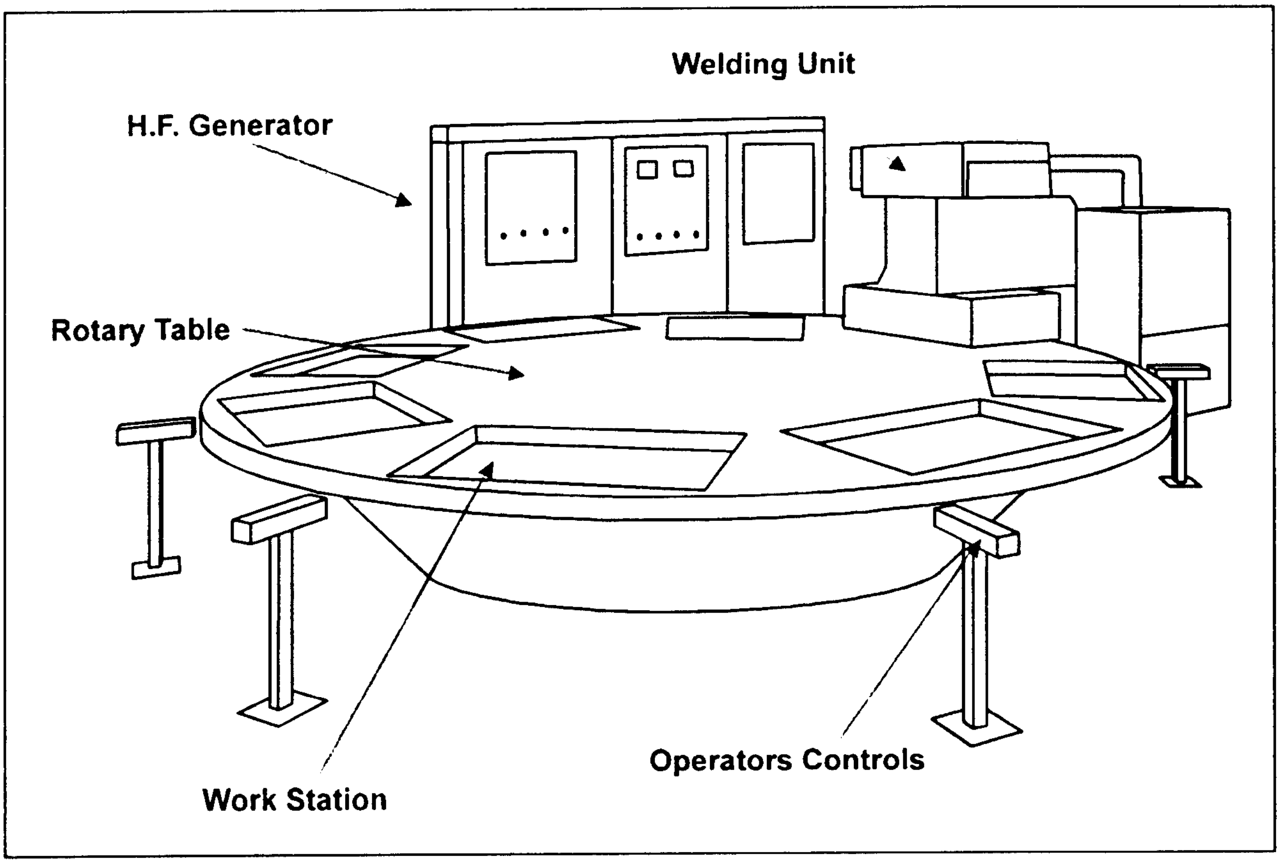

Fig 3-3 - Rotary Table Welding Machine

3.4.4 Shuttle Operated

A typical side-to-side Shuttle operated machine is shown in Fig 3-4. The lower platen comprises two linked shuttle trays. Workpieces are prepared for welding in the shuttle trays. One tray is then moved under the welding head and the weld performed. After welding, the shuttle tray is moved away from the welding head and the other tray is moved under the welding head. This type of machine enables two operators to prepare and finish products using only one welding head.

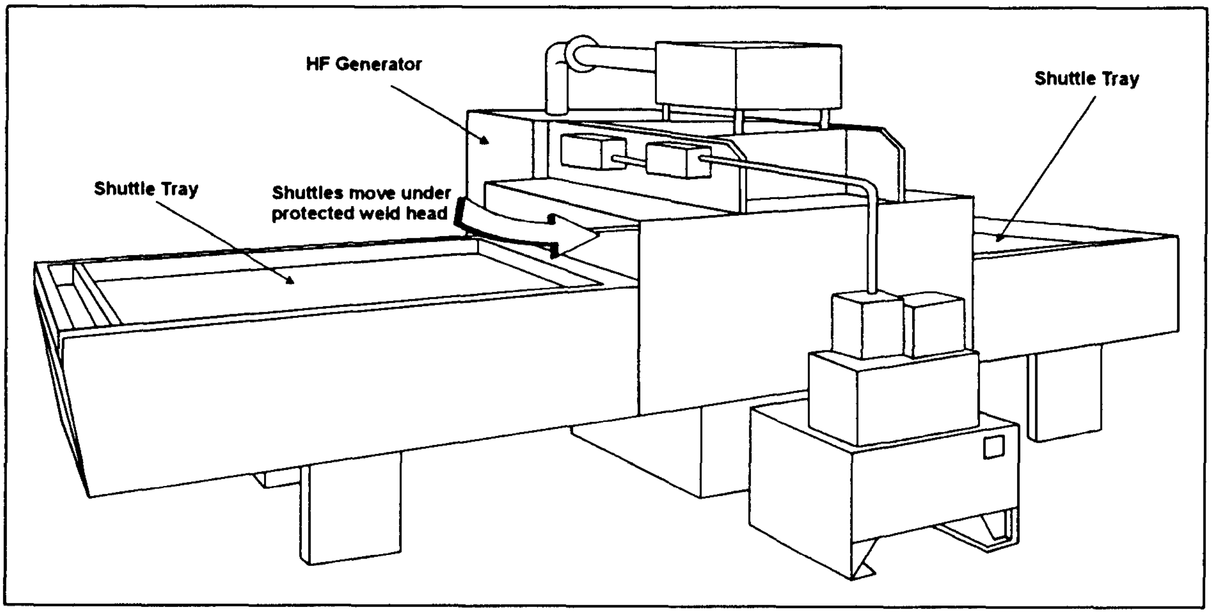

Fig 3-4 - Side-to-Side Shuttle Welding Machine

Another version of this type of machine is the up-and-over shuttle where the two trays are arranged one above the other. This allows an operator to prepare and finish products on one tray while the other is under the welding head.

With auto tuning fitted to allow independent loading for each tray and with electrodes mounted in the trays, a different product can be made in each tray in alternate cycles.

3.5 TOOLING

Tooling is the part of the machine which is pressed onto the workpieces to perform the weld. A typical simple tooling assembly is shown below. This type of tooling is widely used by the HF welding industry for the production of small items, for example stationery binders, presentation folders etc.

The tooling is usually attached to a machine's upper platen. However, if the construction of the workpieces requires it, the tooling can be attached to the lower platen or in the tray.

3.5.1 Tooling Assembly

The tooling assembly, shown in Fig 3-5, comprises a tool plate on which is mounted a shaped strip of welding rule supported by lengths of aluminium fixing bracket. The area enclosed by the welding rule is filled with packing.

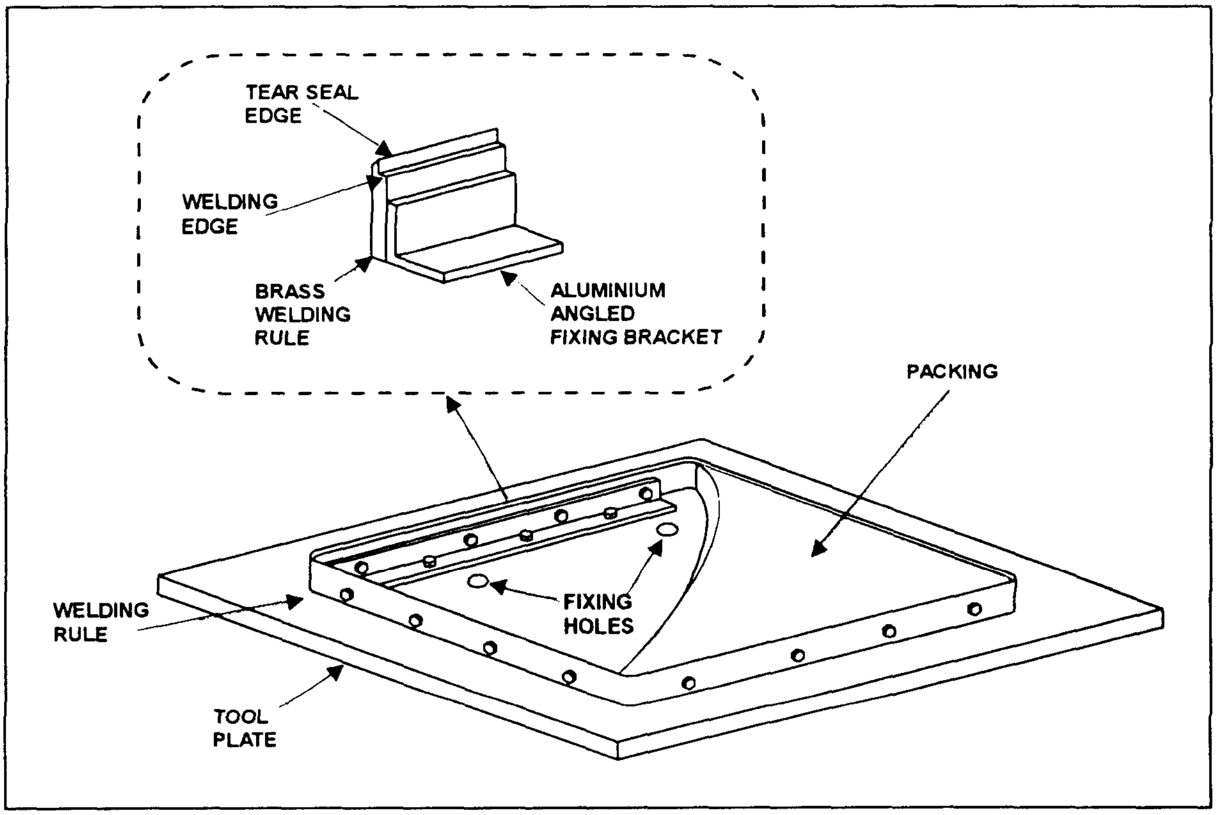

Fig 3-5 - Tooling Assembly

The tool plate is made from sheet aluminium, which must be rigid enough to withstand the pressures applied during the welding process without distorting. For small tooling assemblies, as shown above, 3 mm plate is commonly used. The tool plate incorporates a number of fixing holes to enable it to be bolted to the platen.

3.5.2 Welding Rule

The welding rule is made from brass strip and is available in a wide range of profiles to enable a variety of welds to be performed. There are two main classes of welding rule as shown in Fig 3-6.

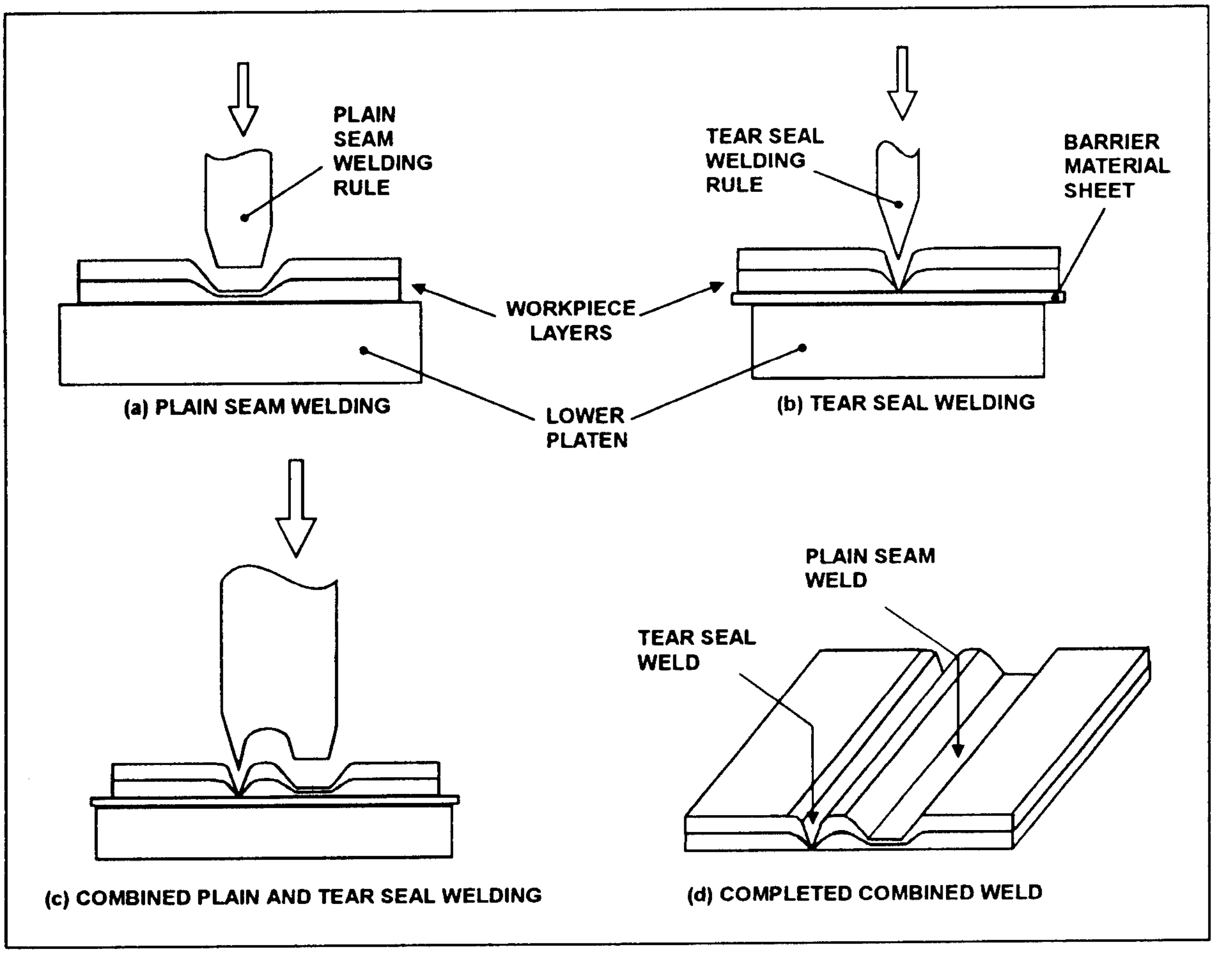

Fig 3-6 - Plain and Tear-Seal Welding Rule

a) Plain seam - shown in Fig 3-6 (a), a flat profile to weld two or more thicknesses of workpiece material together. This type of weld is used to produce folds, e.g. where the finished item is to be allowed to bend, and can also be used to produce decorative panels by machining the face of the profile with a pattern.

b) Tear seal - shown in Fig 3-6 (b). a pointed profile which highly compresses the heated workpiece materials. After welding, the seam produced is so thin that it can torn to enable the workpieces to be separated from the surrounding material.

Note that the tear seal edge of the profile is pointed, i.e. sharp similar to a knife blade, and if it were allowed to come too close to the lower platen, there would be a risk of arcing and consequent damage to the edge. Also, if the edge were allowed to touch the lower platen, it would become blunted. To eliminate these risks, a layer of barrier material is placed between the workpieces and the lower platen. In addition to its protective properties, the barrier material acts as a heat insulator, reducing the heat loss from the workpieces thus improving the efficiency of the weld process.

A common type of welding rule is a combination of the plain and tear seal profiles, shown in Fig 3-6 (c). This produces a plain weld adjacent to a tear seal weld, providing a 'neat' edge to the workpieces which can be stripped from the surrounding material as shown in Fig 3-6 (d).

An example of a typical tear seal welding process is to weld two layers of PVC, each 350 microns thick. During the weld in the plain weld section of a tear seal weld, the layers are compressed to a combined thickness equal to the thickness of a single layer, in this case to 350 microns.

The ratio of the compressed thickness of the welded area to the combined thickness of the original layers is known as the welding differential and is determined by the design of the welding rule. i.e. the ratio of the 'height' of the plain weld profile to that of the tear seal edge.

In practice, the welding differential is set within a range of approximately 50% to 66%. This ratio is an approximation and depends on the materials to be welded.

If a weld area includes a change of the number of layers to be welded, a stepped welding differential can be used to ensure that the thickness of the welded area is uniform. Alternatively, an angled differential where the differential is gradually changed (tapered) as the number of layers is increased/decreased, can be used. The decision to use a stepped or angled differential depends on the type of product and the required finish.

Note that the inside edge of welding rules must be rounded. If they are square, they can cut into the PVC as it is pulled taut during welding, causing it to split and possibly flash over during welding.

3.5.3 Packing

The tooling area enclosed by the welding rule is filled with a foam packing material for some products, e.g. binders. The purpose of the packing is to support the workpiece during the welding process to ensure that:

(a) All air between the workpieces is expelled before the weld is completed.

(b) The areas of the workpieces, close to the welds, are held together firmly to prevent splitting during the welding process.

To provide maximum support for the workpiece, the packing should fill the area enclosed by the welding rule without actually coming into contact with the welding rule profile. In practice, the top of the packing should be slightly above the top of the welding rule profile and the gap between the edge of the packing and the welding rule should not exceed 0.5 mm at any point.

Note that for some other applications where support (but not compression as provided by a foam material) is required, other types of packing materials, e.g. Acetol or Tufnol are used.

3.6 PREPARATION FOR WELDING

Before welding, the workpiece materials and components to be inserted must be prepared and assembled. The actual procedure used depends on the type of welding process, but in the manufacture of stationery items, such as binders, clipboards etc., the following is typical:

1. The PVC sheeting, usually supplied on rolls, is slit and guillotined to produce the workpiece panels. The roll material is fed into a slitting machine which has a number of blades set parallel with the direction of travel of the material. As the material passes the blades it is cut into strips of the correct width for the welding process. After slitting, the material is cut to length in a guillotine. Both of these operations can be carried out sequentially by a panelling machine.

2. The grey board to be inserted is cut to size in a guillotine and corners which will be at the outer edges of the finished product are rounded.

   NOTE: It is important to allow sufficient time between cutting and welding for the PVC to shrink.

3. The PVC workpieces and grey board inserts are assembled and aligned on the work table for welding.

Aligning the workpieces and inserts correctly ensures that the weld is carried out at the required location on the workpieces with respect to the inserts. If more than one welding operation is required, the same alignment datum must be used for all following operations.

Practical alignment is achieved by the use of alignment edges and jigs on the work table.

A simple alignment arrangement as used in the manufacture of stationery binders is shown in Fig 3-7. The alignment edges are used to locate the workpieces and the jig locates the three pieces of grey board that form the cover stiffeners and spine of the binder.

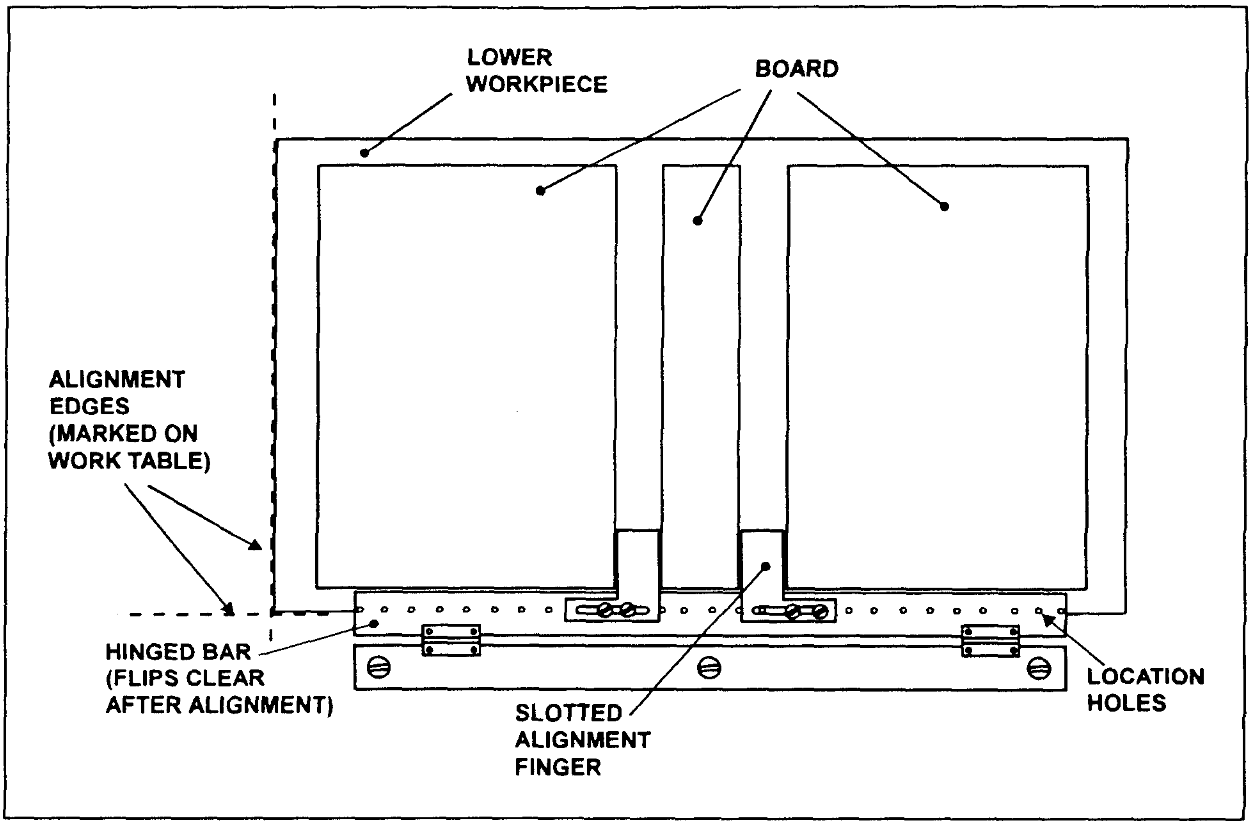

Fig 3-7 - Simple Jig For Aligning Board in a Binder

This jig comprises a pair of bars hinged together, *Typically, 24-inch lengths of welding* rule are hinged together to form the jig. One of the bars is fixed to the work table and the other is drilled with a series of threaded location holes to enable slotted alignment fingers to be positioned anywhere along the length of the bar. Once the jig has been set up for the job, it is used as follows:

1. The hinged bar is flipped clear of the work area.
2. The lower workpiece is laid on the work table against the alignment edges.
3. The hinged bar is flipped on top of the lower workpiece.
4. The three grey boards are aligned with the alignment fingers.
5. The hinged bar is flipped clear of the workpiece.
6. The upper workpiece is laid on the work table against the alignment edges.
7. The welding operation is carried out.

Jigs similar to that shown can be constructed to align components further away from the edge of the workpiece. For short production runs, temporary jigs can be constructed from cardboard, using an adhesive tape as the hinge.

Note that a metal jig close to an electrode can absorb HF energy. Where an HF *welding machine is operated close to its maximum rating this absorption may be* significant enough to reduce the weld quality. In these circumstances, jigs made from non-metallic materials should be considered.