HIGH FREQUENCY WELDING HANDBOOK II part
4. HF WELDING TECHNIQUES

This section gives information on machine setting, weld area calculations and Appliqué welding.

4. MACHINE SETTING

4.1.1 Preparation

Setting a machine is first carried out when a new job is started and comprises the following main stages:

1. Selecting and fitting the tooling plate to the upper electrode.
2. Selecting and fitting the appropriate barrier material.
3. For linear indexing machines, feeding the workpiece webs from the reels through the machine.
4. Ensuring that there is sufficient supply of materials and other required components to hand.
5. Setting the machine controls to obtain the optimum weld.

Once the machine is in use, the settings are checked periodically, e.g. hourly or once a shift. During operation, if the quality of the welded products become unsatisfactory the cause should be investigated and the machine adjusted/repaired accordingly.

4.1.2 Setting the Controls

The Setting Adjustments required will vary from machine and will also depend on the type of work to be carried out. The flow chart shown in Fig. 4-1 gives a typical set up sequence.
4.2 WELD AREA CALCULATIONS

The HF power required to weld a given area depends upon a number of factors. In this sub-section, these factors will be described briefly and the relationship between HF power and weld area will be discussed. The formulae given should be regarded as a ‘rule of thumb’ from which to start setting the HF power level.

4.2.1 HF Genetator Considerations

HF generators have a standing (quiescent) current, or base energy consumption which is required to supply the electrical circuits in readiness for welding. The base energy consumption is approximately 5% of the rated energy output and is taken from the incoming electrical supply during the whole period the welding machine circuits are energised.

The remaining available power (i.e. that above the base energy consumption) provides a weld area that is approximately proportional to the generator output. For example, a 6kW generator is capable of welding an area approximately twice that of a 3kW generator.
The efficiency of an HF generator is approximately 60%. This means that of the input power, 40% (including the base energy consumption) is dissipated as heat in the electrical circuits leaving 60% to be converted into HF power. Therefore a machine with a rated output of 6kW will require a supply of 10kW when operating at its maximum power output.

The maximum power output is only achieved when the electrode sinks into the workpiece materials. Thus during the period when the HF power is applied for the weld, the average power supplied to the electrode is considerably less than the maximum power output. Also, when taking the cooling time and time for unloading and loading components into account, the overall power consumption is a small fraction of that taken when the output power is at its maximum.

4.2.2 Basic Calculation of Required Power

The relationship between a given workpiece area and the HF power necessary to weld it has been established as typically 25 cm per Kilowatt. This is an approximation based on welding two thicknesses of 0.010” (0.254 mm) PVC with a relatively wide plain electrode. In practice, depending on the factors discussed later, the welded area achieved per Kilowatt could be between 10 and 30 cm or 2 to 5 inches.

To achieve a more realistic estimation of the weld area per Kilowatt, the following factors which affect the actual power requirement must be taken into consideration:

(a) Area of Weld
   Approximately directly proportional to required power.

(b) Type of Material
   The higher the loss factor of the material, the lower the power requirement.

(c) Thickness of Material
   The thicker the PVC, the lower the power requirement due to reduced heat losses.

(d) Edge Factor
   This is the total edge length of the welding electrode. A long narrow electrode requires more power than a wide electrode of the same area.

(e) Length of Tear and Seal Edge (if any)
   Tear seal edges require more power than plain welds.

(f) Thickness and Type Of Barrier Material
   Less power is normally required when barrier materials are used but increased electrode voltage will be necessary.

(g) Type and Design Of Electrode
   The heat conductivity of the electrode, whether it is temperature controlled and whether it incorporates components which absorb HF power.

(h) Required Welding Time
   The shorter the required time, the larger the required power, but limiting factors also apply to avoid flashing at the electrode.

Consider the example quoted earlier of two thicknesses of 0.010” (0.254 mm) PVC with a relatively wide plain electrode requiring 1kW to weld 25 cm. For the same weld area using a tear seal weld on 0.005” (0.127 mm) PVC with a low vinyl content, only 0.5 kW would be required.

4.2.3 Realistic Calculation of Required HF Power

Based on some of the more important factors affecting the power requirement for a given weld configuration, a more realistic formula has been developed as follows:
Where

L = Length of weld in inches

D = Width of weld in inches plus 1/16" for tear seal electrodes

E = Watts loss per inch of electrode edge

S = Square inches of weld per kW

The value of the E and S variables depend on the thickness of the material being welded; for PVC, E and S are as follows:

<table>
<thead>
<tr>
<th>PVC THICKNESS</th>
<th>inches</th>
<th>E</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 0.004</td>
<td>2 x 0.1016</td>
<td>3.0</td>
<td>2.0</td>
</tr>
<tr>
<td>2 x 0.005</td>
<td>2 x 0.1270</td>
<td>3.0</td>
<td>2.4</td>
</tr>
<tr>
<td>2 x 0.008</td>
<td>2 x 0.2032</td>
<td>3.5</td>
<td>3.4</td>
</tr>
<tr>
<td>2 x 0.012</td>
<td>2 x 0.254</td>
<td>4.0</td>
<td>4.2</td>
</tr>
<tr>
<td>2 x 0.20</td>
<td>2 x 0.508</td>
<td>5.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

HF Power / Weld Area Examples

The following table lists some examples calculated using the ‘realistic’ formula. Metric equivalents are shown in brackets.

<table>
<thead>
<tr>
<th>SHEETING THICKNESS</th>
<th>WELD WIDTH</th>
<th>INCHES/kW</th>
<th>SQUARE INCHES/kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1&quot; (25.4 mm)</td>
<td>2.36 (59.9 mm)</td>
<td>2.36 (15.27 cm²)</td>
</tr>
<tr>
<td>2 x 0.01&quot; (0.254 mm)</td>
<td>2&quot; (51.0 mm)</td>
<td>4.75 (122.8 mm)</td>
<td>4.75 (30.65 cm²)</td>
</tr>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1/16&quot; (1.56 mm)</td>
<td>9.11 (231 mm)</td>
<td>2.27 (14.66 cm²)</td>
</tr>
<tr>
<td>2 x 0.012&quot; (0.305 mm)</td>
<td>1/8&quot; (3.175 mm)</td>
<td>14.8 (378 mm)</td>
<td>3.7 (23.87 cm²)</td>
</tr>
<tr>
<td>2 x 0.012&quot; (0.305 mm)</td>
<td>3/32&quot; (2.44 mm)</td>
<td>17.1 (436 mm)</td>
<td>4.25 (27.4 cm²)</td>
</tr>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1/16&quot; (1.56 mm)</td>
<td>26.4 (670 mm)</td>
<td>3.3 (21.9 cm²)</td>
</tr>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1/8&quot; (3.175 mm)</td>
<td>30 (762 mm)</td>
<td>3.75 (24.19 cm²)</td>
</tr>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1/16&quot; (1.56 mm)</td>
<td>22 (559 mm)</td>
<td>1.37 (8.84 cm²)</td>
</tr>
<tr>
<td>2 x 0.004&quot; (0.1016 mm)</td>
<td>1/8&quot; (3.175 mm)</td>
<td>25.8 (655 mm)</td>
<td>1.02 (6.45 cm²)</td>
</tr>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1/16&quot; (1.56 mm)</td>
<td>30.4 (772 mm)</td>
<td>1.9 (12.38 cm²)</td>
</tr>
<tr>
<td>2 x 0.004&quot; (0.1016 mm)</td>
<td>1/8&quot; (3.175 mm)</td>
<td>39.2 (996 mm)</td>
<td>2.45 (15.6 cm²)</td>
</tr>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1/16&quot; (1.56 mm)</td>
<td>43.5 (1104 mm)</td>
<td>2.7 (17.4 cm²)</td>
</tr>
<tr>
<td>2 x 0.005&quot; (0.127 mm)</td>
<td>1/8&quot; (3.175 mm)</td>
<td>45 (1143 mm)</td>
<td>2.8 (18.1 cm²)</td>
</tr>
</tbody>
</table>

Additional Factors to Consider

The ‘realistic’ formula is still very approximate and does not take into account many other factors such as:

(a) Generator Operating Frequency
Generators operating at, for example 50 MHz or 70 MHz will give better results on thin materials.

(b) Electrode
With electrodes at temperature appreciably above that of the PVC being welded, less power is required;

(c) Temperature
The heat losses into the electrode during a weld are reduced, thus achieving more weld area.

Calculation Examples
Example 1

To make tarpaulins using two overlapping pieces of 0.5 mm thick PVC with an electrode of 100 cm long x 2 cm wide, with a straight bar weld:

Area of weld: 100 cm x 2 cm = 200 cm

For 2 x 0.5 mm PVC use 25 cm/kW

Power required: (200-25) kW = 8kW

Example 2

Manufacturing an A4 book binder with two pieces of 0.25 mm thick PVC, with tear seal perimeter, on an automatic machine:

Area of perimeter: 160 cm x 2.5 mm = 40 cm

Extra 1.5 mm width for tear seal: 160 cm x 1.5 mm = 24 cm

Area of two spine bar weld: 60 mm x 4 mm each 4 mm wide = 24 cm

Total area = 88 cm

For 2 x 0.25 mm PVC on an automatic machine allow 22 cm/kW

Power required: (88 – 22) kW = 4 Kw
4.3 APPLIQUE’ WELDING

Appliqué decoration is an age-old method of ornamentation whereby one piece of material is cut out and attached to the surface of another. It might be found on a shield or a suit of armour, but more often as a decorative fabric stitched to another woven material.

Using PVC sheeting a decorative material permits HF bonding as a method of attachment to woven fabrics by mechanical bonding of melted PVC pushed between the threads or directly onto another PVC sheet. This attachment technique can be plain welding and it is easy to see the attraction of the next logical step, emulating tear-seal welding, which is to arrange for surplus PVC to be stripped away all around the tool impression.

A stripping tear may be found to be more easily started from a scissors cut into the surplus material toward the impressed profile, with the surplus PVC pulled horizontally over the impressed surface rather than directly away from the work piece.

4.3.1 Cost

Very impressive examples of appliqué welding have been produced, even including several colours of decorative PVC in the same impression, which show just what is possible with skilfully applied technique. Good results cannot be obtained with inappropriate technique anyway, but even when a tool and machine set-up is perfect the most important factor affecting the cost of processing is the time required for hand stripping and finishing when the work has left the welding machine.

4.3.2 Applications

The process can produce delicate and fancy decoration, most of its commercial appeal lies in reproducing striking simple artwork requiring little subsequent hand finishing.

4.3.3 Welding

Complications arising from fancy shapes and small size mean that most appliqué tools cannot be fabricated using bent brass rule bracketed to a baseplate. Where this construction is used the toolmaking must be meticulously accurate so far as the plane of the welding edges in concerned. For this reason they are best built directly on to thick baseplates rather than thin soleplates which may rely on welding pressure to flatten any residual curvature against their backing plates: this will not happen in appliqué welding where precise depth of sink control is essential.

We know that a pointed edge will cut through soft sheeting when sufficient force is applied to it, and in tear-seal welding this is undesirable until the temperature of the work material is raised by HF heating. However, in appliqué welding it seems there can be a distinct advantage when some mechanical cutting occurs before, or very early in the HF heating phase. To get this benefit we need to arrange that:

(a) the PVC is soft enough.

(b) tool pressure is appropriate.

5. MAINTENANCE

The maintenance of HF welding machines falls into two categories, preventive maintenance and faultfinding/repair.

Preventive maintenance is the regular cleaning, lubrication, inspection and testing of a machine to keep it in good working order and to prevent breakdowns.
Faultfinding and repair are carried out after a machine has broken down or is not operating correctly, to restore the machine to good working order.

Preventive maintenance is discussed in this section and fault finding on machines and welds is discussed is Section 6.

5.1 PREVENTIVE MAINTENANCE

One aspect of HF welding which is often overlooked, is the regular maintenance of the welding machinery. Regular checks on the machinery can often reveal potential problems well before any damage is caused. This will minimise any downtime cause by damage to the machines, and expensive component renewal. The important rule is “prevention is better than cure!”

To ensure that maintenance is not overlooked, it is suggested that a maintenance schedule is drawn up for each machine. The simply lists the maintenance tasks and how often they need to be carried out. For maintenance details of specific machines, read the manufacturer’s manuals supplied with the machine.

WARNINGS

1. MAINTENANCE MUST ONLY BE CARRIED OUT BY PERSONNEL QUALIFIED TO DO SO AND WHO ARE AWARE OF THE RISKS INVOLVED.

2. WELDING MACHINES ARE SUPPLIED WITH ELECTRICAL SUPPLIES WHICH CAN BE LETHAL. THEREFORE ANY MAINTENANCE ON ELECTRICAL CIRCUITS MUST ONLY BE CARRIED OUT BY QUALIFIED ELECTRICIANS.

3. DO NOT REMOVE ANY COVERS OR PANELS FROM ELECTRICAL CIRCUITS UNLESS:

   (A) THE RELEVANT ELECTRICAL ISOLATOR(S) HAVE BEEN LOCKED OFF AS REQUIRED BY SECTION 12 OF THE ELECTRICITY AT WORK REGULATIONS.

   (B) ANY STORED ENERGY HAS BEEN DISSIPATED OR DISCHARGED TO EARTH.

5.1.1 Cleaning

To ensure that a machine continues to operate efficiently and safety it must be kept clean and free from debris. Moving parts can become obstructed, preventing smooth operation of the machine and changing setting adjustments. Electric motors and air intakes to HF generators can become clogged with debris, causing overheating and a potential fire hazard.

The work area around machines should also be kept clean and tidy to minimise the risks of personnel slipping, tripping etc.

5.1.2 Lubrication

To ensure the smooth running, and long life, of any mechanical system, including welding machines, lubrication is essential. All lubrication should be carried out in accordance with the manufacturers instructions at the specified lubricants. Generally, lubrication should cover the following items:

   a) Oil levels in gearboxes, dashpots etc. should be checked weekly. Follow the manufacturer’s instructions regarding oil and filter changes, ensuring that the specified lubricants and components are used.

   b) Drive chains and shaft should be lubricated sparingly as recommended by the manufacturer.

   c) Grease nipples and lubrication points should be lubricated as recommended by the manufacturer.

5.1.3 Inspection

For the safe running of any welding machine, there should be regular inspections to check the following:
a) All safety guards are functional and fitted correctly.

b) All drive chains and drive belts are undamaged, fitted correctly and tensioned correctly.

c) All wiring is routed safely and is undamaged.

d) All electrical connections are secure.

e) All air intakes are free from obstruction.

5.1.4 Testing

The welding machines should be regularly tested. These tests should check all aspects of the machine’s operation. For example, they should be checked to ensure that they operate correctly and safely, and at all times conform to any local safety standards including levels of RF emissions.

6. FAULT FINDING

This section gives help for fault finding on HF welding machines and welds.

The fault finding on machines is limited to general problems which should be easily solved by trained personnel. For detailed fault finding refer to the machine manufacturer’s maintenance manuals.

6.1 HF WELDING MACHINES

 WARNINGS

1. FAULT FINDING MUST ONLY BE CARRIED OUT BY PERSONNEL QUALIFIED TO DO SO AND WHO ARE AWARE OF THE RISKS INVOLVED.

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The following fault finding charts are for general guidance only, they are not exhaustive and are only intended as a guide through typical fault finding sequences.
<table>
<thead>
<tr>
<th>SYMPTOM</th>
<th>POSSIBLE CAUSE</th>
<th>ACTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power On indicator unlit</td>
<td>1. Electrical supply to machine not switched on.</td>
<td>Check the main incoming circuit breaker and Power On switch.</td>
</tr>
<tr>
<td></td>
<td>2. Fuse blown or circuit breaker tripped.</td>
<td>Check fuses and circuit breakers. If blown or tripped, investigate the cause and repair any fault before replacing fuse or remaking a circuit breaker.</td>
</tr>
<tr>
<td></td>
<td>3. Wiring open circuit or loose/broken electrical connections.</td>
<td>Check wiring, terminals and switches.</td>
</tr>
<tr>
<td>Power available but machine does not run.</td>
<td>1. Safety interlock open circuit.</td>
<td>Check that all guards are correctly fitted and that any interlocked panels are in place.</td>
</tr>
<tr>
<td></td>
<td>2. Emergency Off pushbutton pressed in.</td>
<td>Check that all Emergency Off pushbuttons are released. To release twist the pushbutton and pull outwards.</td>
</tr>
<tr>
<td></td>
<td>3. Process interlock open circuit.</td>
<td>Check the function of all mechanical, thermal and flow interlocks.</td>
</tr>
<tr>
<td></td>
<td>4. Mechanical 'jam'</td>
<td>Check that all mechanical moving parts are free to move and are unobstructed. Especially check for jammed workpieces or other product components.</td>
</tr>
</tbody>
</table>

Fig 6-1 – Typical Welding Machine Fault Finding Sequence Flow Chart

6.2 WELDS

The weld fault finding chart shown in Fig 6-2 lists weld faults and their possible causes.
### FAULTS

<table>
<thead>
<tr>
<th>Fault Description</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld opens up</td>
<td>+</td>
</tr>
<tr>
<td>Film breaks on edge of weld</td>
<td>+</td>
</tr>
<tr>
<td>Film breaks within weld</td>
<td>×</td>
</tr>
<tr>
<td>Poor resistance to tear propagation</td>
<td>+</td>
</tr>
<tr>
<td>Bursting of tear seal on inflation</td>
<td>+</td>
</tr>
<tr>
<td>Tear seal not properly welded (ragged tear line)</td>
<td>×</td>
</tr>
<tr>
<td>Deformed welds</td>
<td>×</td>
</tr>
<tr>
<td>Formation of bulges and blisters on reverse side of weld</td>
<td>×</td>
</tr>
<tr>
<td>Poor weld impression and variation within weld</td>
<td>×</td>
</tr>
<tr>
<td>Gloss variation next to weld</td>
<td>×</td>
</tr>
<tr>
<td>Air inclusion in welded articles with card inserts</td>
<td>×</td>
</tr>
<tr>
<td>Formation of folds (corrugation)</td>
<td>×</td>
</tr>
<tr>
<td>Tendency to string (especially with thin or rigid films)</td>
<td>×</td>
</tr>
<tr>
<td>Surface cracking</td>
<td>×</td>
</tr>
<tr>
<td>Large surface welding (Differential energy distribution)</td>
<td>×</td>
</tr>
</tbody>
</table>

X = Refers only to the bonding of film to coated boards

### CAUSES KEY

<table>
<thead>
<tr>
<th>Fault</th>
<th>Cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>HF output insufficient</td>
</tr>
<tr>
<td>2</td>
<td>HF output too high</td>
</tr>
<tr>
<td>3</td>
<td>Welding time too short</td>
</tr>
<tr>
<td>4</td>
<td>Welding time too long</td>
</tr>
<tr>
<td>5</td>
<td>Cooling time too short</td>
</tr>
<tr>
<td>6</td>
<td>Pressure too low</td>
</tr>
<tr>
<td>7</td>
<td>Pressure too high</td>
</tr>
<tr>
<td>8</td>
<td>Depth stop incorrectly set</td>
</tr>
<tr>
<td>9</td>
<td>Electrode too narrow</td>
</tr>
<tr>
<td>10</td>
<td>Electrode too wide</td>
</tr>
<tr>
<td>11</td>
<td>Back cover spine weld too narrow</td>
</tr>
<tr>
<td>12</td>
<td>Faulty weld design</td>
</tr>
<tr>
<td>13</td>
<td>Edge of weld too sharp</td>
</tr>
<tr>
<td>14</td>
<td>Electrode penetrates too deeply (especially on faking welds)</td>
</tr>
<tr>
<td>15</td>
<td>Difference in height of weld to tear seal too small</td>
</tr>
<tr>
<td>16</td>
<td>Difference in height of weld to tear seal too high</td>
</tr>
<tr>
<td>17</td>
<td>Height of electrodes does not match differential thickness of layer</td>
</tr>
<tr>
<td>18</td>
<td>Tear seal too blunt</td>
</tr>
<tr>
<td>19</td>
<td>Tear seal too sharp</td>
</tr>
<tr>
<td>20</td>
<td>Temperature of electrode too low (where heater box is used)</td>
</tr>
<tr>
<td>21</td>
<td>Temperature of electrode too high (where heater box is used)</td>
</tr>
<tr>
<td>22</td>
<td>Temperature variation over electrode area (i.e., hot spots and cold spots)</td>
</tr>
<tr>
<td>23</td>
<td>Conductive printing inks</td>
</tr>
<tr>
<td>24</td>
<td>Insufficient rigidity in electrode mountings</td>
</tr>
<tr>
<td>25</td>
<td>Unsuitable barrier material</td>
</tr>
<tr>
<td>26</td>
<td>Thermal barrier material too thick</td>
</tr>
<tr>
<td>27</td>
<td>Film too brittle</td>
</tr>
<tr>
<td>28</td>
<td>Card inserted too tightly</td>
</tr>
<tr>
<td>29</td>
<td>Tension due to shrinkage of film</td>
</tr>
<tr>
<td>30</td>
<td>Excessive stress</td>
</tr>
<tr>
<td>31</td>
<td>Wear on electrode</td>
</tr>
<tr>
<td>32</td>
<td>Delamination of surface coatings</td>
</tr>
<tr>
<td>33</td>
<td>Film not dehydrated</td>
</tr>
<tr>
<td>34</td>
<td>Film stuck to film</td>
</tr>
<tr>
<td>35</td>
<td>Conductive printing inks</td>
</tr>
<tr>
<td>36</td>
<td>Film contains impurities (recycling)</td>
</tr>
<tr>
<td>37</td>
<td>Packaged material electrically conductive</td>
</tr>
<tr>
<td>38</td>
<td>Layers of different hardness</td>
</tr>
<tr>
<td>39</td>
<td>Material layers too thick in contour (tear-seal) welding</td>
</tr>
<tr>
<td>40</td>
<td>Film tends to curve</td>
</tr>
<tr>
<td>41</td>
<td>Film consistency to gloss</td>
</tr>
<tr>
<td>42</td>
<td>Missing or insufficient packing</td>
</tr>
<tr>
<td>43</td>
<td>Card inserted too tightly</td>
</tr>
<tr>
<td>44</td>
<td>Film not dehydrated</td>
</tr>
<tr>
<td>45</td>
<td>Poorly oriented orientation of film</td>
</tr>
<tr>
<td>46</td>
<td>Film used have greatly different thickness</td>
</tr>
<tr>
<td>47</td>
<td>If adhesive coated, type of adhesive unsuitable</td>
</tr>
<tr>
<td>48</td>
<td>Excessive weld area/generator output ratio</td>
</tr>
<tr>
<td>49</td>
<td>Too small weld area/generator output ratio</td>
</tr>
<tr>
<td>50</td>
<td>Unfavorable generator characteristics</td>
</tr>
<tr>
<td>51</td>
<td>Material unsuitable for welding</td>
</tr>
<tr>
<td>52</td>
<td>Maladjusted standing wave generators</td>
</tr>
</tbody>
</table>
7. MATERIALS USED IN HF WELDING

The following materials are used in HF welding:

(a) Thin sheeting  Typical minimum gauge 70 microns, plain, coloured, printed, embossed or unembossed.

(b) Thick sheeting  Typical maximum single ply gauge 750 microns, but can be laminated to 1.5mm and above. Plain, coloured, printed, embossed or unembossed.

(c) Unsupported Rigid PVC  Typical Thickness 150 to 500 micron in roll form or up to 750 micron in panel form.

(d) Net reinforced  Laminated PVC plies, containing a reinforcing net. Ranging from very open net constructions to very close constructions.

(e) Coated Fabrics  Cotton or synthetic woven fabrics, coated on one or both sides with a PVC composition.

NOTE: See Appendix B for details of Chemical Names, Trade Names and Abbreviations used for materials used in the HF Welding industry.

7.1 NATURE AND PROPERTIES OF PVC

The letters ‘PVC’ stand for polyvinyl chloride. PVC is any material or product made of a PVC composition, i.e. of an intimate mixture of a vinyl chloride polymer or copolymer with various additives, some of which (e.g. plasticisers in a flexible PVC composition) may be present in significant proportion.

PVC is a thermoplastic material, i.e. when heated it softens. This allows it to be processed by calendaring, extrusion, injection moulding, vacuum forming, pressing etc.

7.2 PVC CHEMICAL STRUCTURE

The basic repeat unit of the PVC polymer chain is:

Where \( n \) is the number of repeat units in the molecular chain. The units are linked virtually exclusively ‘head to tail’.

For commercial PVC polymers the average values of \( n \) range between approximately 500 and 1500.

7.3 PVC COMPOSITIONS

PVC cannot be processed as it is supplied. Various additives are mixed with it to allow it to be processed and to achieve the require properties.

7.3.1 Rigid PVC Compounds

Rigid plastic compounds are composed of polyvinyl chloride and the necessary compounding ingredients such as lubricants, stabilisers, impact modifiers and pigments essential for processing, property control and colouring.
7.3.2 Flexible PVC Compounds

These are manufactured from polyvinyl chloride and the necessary compounding ingredients such as plasticisers, stabilisers, lubricants, fillers and pigments.

7.3.3 Additives used in the Industry

(a) PVC suspension polymers.

(b) Plasticisers – Used in varying quantities for different flexibility. Note that plasticisers not only make PVC sheeting soft and flexible, but also enable HF welding to be carried out much more easily and with less power required.

(i) Phthalate based, e.g. Di Octyl Phthalate (DOP) and Di-Isoc Decyl Phthalate (DIDP).

(ii) Low temperature plasticisers to achieve low temperature properties, e.g. Adipates.

(iii) Fire retardant plasticisers e.g. Phosphate.

(iv) Polymeric Plasticisers – long chain structures to achieve good extraction resistance, e.g. washing/bolling.

(v) Stabilisers – based on metals such as Lead, Barium, Zinc, and Tin. Used to enable PVC to be processed and to give end use stability.

(vi) Lubricants – used in conjunction with stabilisers to enable ease of processing, i.e. prevents the PVC from sticking to hot metal surfaces.

(vii) Fillers – based on calcium carbonate in the main and used to reduce formulation costs.

(viii) Pigments – used to colour the compound to give a range of colour and opacity.

(ix) Others – depending on applications:

Impact modifiers – based on MBS/ABS polymers used predominantly in rigid PVC compounds to give strength and vacuum formability.

UV / Antioxidants – to give good outdoor weathering properties.

Antistatic additives – used to reduce static electricity.

Bactericides / Fungicides – used to reduce fungal attack from micro-organisms.

Fire retardant additives – to boost the PVC compounds to give fire retardant properties for the various strict regulations – can be based on antimony, zinc and aluminium compounds.

Process / Matting Agents – can be based on acrylic polymers and other compounds.

7.4 PROPERTIES OF PVC SHEET

The application will determine the necessary additives to be chosen to achieve the necessary specification.

For example, a stationery grade will probably contain:

PVC Polymer, Plasticiser, Stabiliser, lubricant and pigments – a rather basic formulation but the application may demand the use of a combination of plasticisers:

Di Octyl Phthalate (DOP)
Phosphate
Adipate
Together with other additives such as antistatic additives, UV absorbers and bactericides.

The application may also require the careful selection of the metal stabilisers – toxicity i.e. Barium / Zinc based systems predominately but Calcium / Zinc systems are used in medical, nursery and toy applications.

7.5 FACTORS THAT GOVERN A SATISFACTORY WELDED PRODUCT

Good Lay-Flat and Curvature
This means the way a roll of PVC appears when laid out. If inadequate control has been taken when the PVC was produced, the sheet may look ‘baggy’ or have cockled edges. The worst case is when the sheet appears to go round corners, i.e. ‘banana’ effect.

Tear Strength
This means as it says, PVC generally is supplied with good tear strength but this can depend upon the gauge, emboss, formulation and processing temperatures. Poor tear strength could affect the end product or end process when welding.

Appearance Defects
Mainly due to inadequate processing techniques including poor choice of PVC additives, packaging defects etc.

Poor Weldability
A number of reasons can cause this:

• Excessive use of lubricants in the PVC sheet gives a barrier to HF welding performance and strength.
• Contamination either in the sheeting or surface, this could cause arcing at the electrode.
• Poor selection of printing inks and lacquer systems causing poor weld strength performance.
• Excessive use of fillers within the formulation will cause poor weld strength and will require increased power settings compared to unfilled products.
• The degree of flexibility of a PVC sheet can have an influence on weldability – basically the soften the PVC sheet, the less power is required to achieve a good weld. However, it may be found necessary to set the pressure higher on the machine.
• Gauge of PVC sheet is an obvious reason for weld variability but can easily be compensated for.

7.6 TYPES OF PVC SHEET AND THEIR USES

Thin Flexible Medical
Nursery
Protective Clothing
Insulation Tape
Self-Adhesive labels
7.7 THE ROLE OF PLASTICISERS IN FLEXIBLE PVC SHEETING

7.7.1 Introduction

PVC is unusual in many respects when compared with other plastics. It is made from two raw materials, crude oil and common salt. The chlorine component in PVC (derived from salt) makes PVC inherently non-flammable, and enables PVC sheeting to be HF welded (unlike Polythene which has a similar molecular structure apart from the chlorine component).

It is also unusual in that the physical properties (e.g. flexibility) can be dramatically changed by addition of plasticiser. This enables PVC sheeting to be either rigid (when it contains no plasticiser) or very flexible (when it contains a lot of plasticiser) or anywhere between these two extremes. This makes PVC sheeting suitable for many different applications, because the flexibility can be matched precisely to the requirements of each particular product.

7.7.2 Why are a Range of Plasticisers Used?

Plasticisers are synthetic oils which are used to make PVC flexible. The most commonly used plasticiser is Di Octyl Phthalate (DOP), which is used because it is cheap and effective. Most stationery grades of PVC sheeting contain DOP plasticiser. Another standard plasticiser, which again is cheap and effective, is Di-Isoc Decyl Phthalate (DIDP). This has a larger molecular structure than DOP, and when incorporated into PVC sheeting, is more resistant to being extracted by repeated washing or by contact with adhesives. This property is important in such applications as Hospital Sheeting (which must remain soft and flexible in spite of repeated washing) and Self Adhesive Labels.

Even greater extraction resistance is obtained by using Polymeric plasticisers which have a very large molecular structure, but which are very expensive.

One disadvantage of adding these plasticisers is that they are flammable, so that flexible PVC sheeting made using them will burn relatively easily, whereas rigid PVC sheeting containing no plasticiser will not.
By using a Phosphate plasticiser, which has the advantage of being non-flammable, a flexible PVC sheet which is also non-flammable can be made. However, Phosphate plasticiser is only used when necessary since it is more expensive than standard plasticisers.

Low temperature properties (i.e. cold crack) can be significantly improved by the use of Adipate plasticiser, but again there is an increased price to pay for this benefit.

### 7.7.3 What is Plasticiser Migration and Why Does it Happen?

When flexible PVC sheet containing one type of plasticiser (e.g. DOP) is in close contact with rigid PVC sheeting containing no plasticiser at all, then plasticiser tends to move from one sheet to the other. This movement can be compared to water flowing from a full tank to an empty tank until both are half full, and the movement stops.

The movement of plasticiser is relatively slow, and can take several months at room temperature for it to become evident through the distortion it causes. The sheet which loses plasticiser will shrink, and the sheet which gains plasticiser will expand, thus causing the distorted appearance.

When flexible PVC sheets containing different plasticisers are in close contact, plasticiser flows both ways, but the rate of flow depends on the type of plasticiser, if a DOP plasticised sheet is in contact with a DIDP plasticised sheet, then the DOP sheet will lose plasticiser much more rapidly than it gains it from the DIDP sheet, and again distortion will be evident.

A similar distortion of flexible or semi-rigid PVC sheeting can also occur when differential shrinkage takes place. A roll of calendered PVC sheeting always shrinks slightly in the length direction (known as the machine direction) due to the inevitable tension involved when passing down the calender line. This phenomenon is well known in our industry, and causes no problems provided that the welder ensures that the machine direction runs the same way in all layers to be welded together. If the machine direction is not constant for the various layers, then shrinkage of each layer will produce distortion.

### 7.7.4 How Can I Ensure that Plasticiser Migration Does Not Happen?

Plasticiser migration is usually caused by welding together PVC sheets containing different plasticisers.

Most manufacturers have now standardised on the use of DOP plasticiser for stationery grade materials (both flexible and semi-rigid) thus reducing the likelihood of migration problems.

Some welders insist on buying all materials from the same supplier in order to avoid problems. However, any PVC manufacturer worth his salt will regularly monitor competitive products and be able to confirm the compatibility of his various products with other materials. Should non-standard materials be involved, then laboratory testing can rapidly confirm whether they are compatible.

### 7.8 COLD CRACK PROBLEMS WITH STATIONERY PRODUCTS

#### 7.8.1 Introduction

During severe weather conditions, when external temperatures drop to freezing and below, problems are occasionally experienced with the cracking of the PVC covering material on ring file binders and similar products.

#### 7.8.2 Possible Causes

Cold crack is often blamed initially on the PVC material itself, although on further investigation is usually found to be due to other factors, as the following list of possible causes clearly shows.

(a) The PVC Sheeting

PVC is a thermoplastic material and it gets stiffer as its temperature is reduced. Stationery grade PVC is formulated specifically for this application. Sufficient low temperature performance is built in to allow manufacture and use of the finished product at both normal room temperature and at lower temperatures down to freezing point.
All manufacturers of PVC sheeting monitor the low temperature performance of their stationery grade materials. However, the trend during recent years towards the use of stiffer and thinner materials has inevitably reduced their performance at extremely low temperatures. In spite of this, the material should normally be capable of operating at temperatures down to freezing without cracking.

An article by Don Poole in the April ’93 edition of The High Frequency Welder describes in detail how the low temperature properties of PVC sheeting can be further improved, albeit at an increase in cost, by the use of special plasticisers.

(b) Weld Design

The welding tool profile can have a dramatic effect on cold crack problems. If sharp edges are left on the tool instead of being radiussed, this can cause significant weakening of the weld and increase the likelihood of cracking.

(c) Welding Machine Setting

The time/power and depth of sink setting on the welding machine can also have a significant effect on the tendency to give cracking problems.

If excessive heat is used during welding, the material in and around the weld is overheated and the plasticiser is evaporated. (Plasticiser is a high boiling point liquid and can be volatilised just as water can be boiled to steam). This makes the material in and near the weld slightly stiffer, and therefore more likely to crack, than the surrounding material.

If excessive depth of sink is allowed during welding, then the excessive thinning of the weld leads to general weakness in this area.

(d) Transportation of Finished Goods

Finished goods are normally packed in cardboard boxes. If sufficient packing is not included to firmly hold and cushion the products against impact, then the extreme edges of the product may repeatedly rattle against the walls of the box. If this happens when the temperature inside the box is below freezing point, e.g. because the lorry transporting the goods has been left in a lorry park overnight in freezing temperatures, then the finished products may well suffer from cracking problems.

7.8.3 Summary

Cold crack problems are rare, and the majority of cold crack problems which do arise are caused by inadequate care during transportation, sometimes exacerbated by poor weld design / machine setting.

7.9 COLOUR MATCHING OF FLEXIBLE PVC SHEETING

Flexible PVC sheeting is available in a wide range of colours, obtained by blending together various pigments to achieve the required colour shade.

A typical PVC manufacturer regularly uses a palette of some 40 pigments, plus many more which are available as required.

If the required colour shade is not available in the appropriate grade from the standard stock range, then a particular colour shade can be specially matched. This process starts by examining a sample of material in the required shade using a spectrophotometer which measures the light reflected by the sample at all wavelengths across the colour spectrum. This colour measurement is very much easier and more accurate if a PVC sample rather than a printed paper sample, e.g. from a pantone swatch, is available for colour matching.

The spectrophotometer is linked to a computer containing details of the colour shades available from the various combinations of our palette of 40 pigments. The computer can provide several colour match recipes which will achieve the required shade, together with the cost of these recipes. The lowest cost recipe is usually chosen, although a knowledge of the particular application for the material may affect this choice.
A small sample in the required grade of flexible PVC is then prepared using the suggested colour recipe, and checked for colour shade accuracy before submitting to the customer for approval.

The computerised colour matching described above is extremely accurate, and can detect colour shade differences not visible to the eye. It can also produce a printout of the colour spectrum for the required shade, with a superimposed printout of the matched colour for comparison.

Once customer approval of the matched shade has been obtained, a subsequent order can be manufactured using the approved shade as a master sample. Slight colour shade variation is normal during production, but is closely monitored to ensure that all material is within usual commercial tolerance for colour shade.

7.9.1 Opacity of Colour

The opacity of a sample of coloured flexible PVC will depend on the thickness of the PVC sheeting, the amount and type of pigment it contains (which will depend on the particular colour shade), and the amount of filler (if any) which it contains.

It follows that if the thickness of a coloured PVC sheet is reduced by half, then the opacity of the sheet will also be reduced by half. If this is not acceptable, then the opacity can be restored by increasing the amount of (and therefore the cost) of pigment mixture used in manufacture of the sheet, while leaving the blend of pigments (and therefore the colour shade) unchanged.

7.9.2 Types of Pigment used in Flexible PVC Sheeting

Pigments generally fall into two categories, Organic and Inorganic. The Inorganic pigments are based on metallic compounds, e.g. iron oxides (brown), lead oxides (yellow), cadmium compounds (yellow and red), titanium oxides (white) etc. Although these pigments are cheap and effective, those based on heavy metals (i.e. lead and cadmium) are being or have been replaced in view of the health and environmental risks they pose to both manufacturers and users of PVC sheeting.

Organic pigments are based on organic compounds (i.e. containing carbon) and are available in a very wide range of colours, but tend to be more expensive and less heat stable than the equivalent metallic pigments.

7.9.3 Variation in Colour Shade under Different Lighting

When checking colour shade by eye, it is important to bear in mind the lighting conditions being used. Some colour shades can look very different when viewed in daylight compared with their colour under artificial (fluorescent) light. This is known as the Metameric effect and is due to the particular pigments used to achieve the colour shade.

It is therefore important to indicate the intended application for a sample sent for colour matching, so that the colour match is assessed under the most appropriate lighting conditions.

7.10 THE IMPORTANCE OF UNIFORM GAUGE IN CALENDERED PVC SHEETING

7.10.1 Introduction

The process of calendaring is used to produce PVC sheeting of the required thickness and surface finish by passing a hot plastic dough through a set of heated calender rolls. The calender rolls are set up with a fixed gap between them, and exert great pressure on the hot PVC dough as it passes through.

The hot PVC sheet emerges from the calender, passes through the embossing unit where the required surface finish is produced, through cooling rollers and finally wound up into rolls.

All Calenderers aim to produce PVC sheet with absolutely identical thickness right across the full width of the sheet. All manufacturers get as close as possible to this ideal.
7.10.2 Why Does the Gauge Vary?

The basic problem we face is that the great pressure exerted on the hot PVC dough during calendaring is equally exerted on the calender rolls, which distort slightly, particularly in the centre of the roll. If no corrective action was taken, this would produce PVC sheeting thicker in the centre of the sheet than at the edges. In order to compensate for this effect, calender rolls are profiled to a barrel shape with a very slightly larger diameter in the centre of the roll. This profiling is extremely critical and largely determines the uniformity of gauge of PVC sheeting produced, although there are other adjustments which can also be made to help achieve the required uniformity.

7.10.3 What Happens if the Gauge is Not Uniform?

If the gauge varies significantly across the width of the PVC sheet, then poor layflat and possibly curvature will be evident. If the centre of the sheet is slightly thicker than the edges, then billows of excess material will be seen running down the centre of the sheet. If the edges of the sheet are slightly thicker than the centre, then the sheet will have wavy edges. If one edge is slightly thicker than the rest of the sheet, than the material will show curvature, with the thicker edge on the outside of the curve.

These layflat and curvature problems obviously complicate, and in some cases prevent the fabrication of PVC sheeting into finished products.

All manufacturers of PVC sheeting are aware of this, and take great care to produce sheeting with the most uniform gauge possible.

7.10.4 What Quality Control Checks are Carried Out During Manufacture?

All modern PVC calender lines are equipped with gauge measurement devices, although many only measure at three of four positions across the width of the sheet. The most modern equipment measures gauge continuously across the full width of the sheet, and produces a visual display showing any variation from the required gauge. In addition, it is usual to measure the circumference of the finished roll of PVC sheeting (which may vary from 50 to 2000 metres in length) at several points across the width of the roll. This measurement (called a Banding Check) is very sensitive since it records differences in the total thickness of many layers of material rather than minute differences in just one layer. As a final check, a selection of rolls taken throughout the production run are rolled out on an inspection table for visual assessment.
APPENDIX A

A VIEW BACK TO SQUARE ONE IN THE EUROPE

Recognised since the middle of the century as a unique industrial process, HF welding has no recognised inventor. Some ways and means of melting PVC by high frequency electricity seem to have evolved in World War II when PVC became a useful substitute for rubber. It might have happened sooner but calendered PVC was virtually unknown when reliable sources of HF power were devised by the radio industry as short wave broadcasting expanded between the wars. Among the noticeable side effect of a radio transmitter's power were objectionable heating of materials in and around the transmitting equipment and annoying reflections of radiated energy from distant objects which interfered with reception.

Radio echoes were soon put to good use in the first cumbersome radar, but the exploitation of dielectric heating effects is not so well documented. HF generators were certainly used prior to 1939 in medical diathermy equipment for it is reported that some of these were subsequently fitted with antennae to jam German radio signals guiding bombers to English cities. It therefore seems likely that the first ‘marketed’ application of HF heating was for the international warming of live human flesh. Now we have guidelines and legislation to avoid it in an HF welding workplace.

The most famous industrial applications of dielectric heating in the pressure of war appears to be the heating and rapid curing of synthetic resin glues in wooden propellers and aircraft such as the Mosquito. These techniques were ready to be applied in post-war production of furniture and TV cabinets, but very little prior art existed for welding the first calendered PVC which arrived in quantity, with all sorts of claims for its properties. It truly was a wonder material which could imitate expensive fabrics and almost anything else, appearance-wise. Its disadvantage was that sewn were not very strong, or waterproof like the fabric itself.

Vinyl sheeting is thermoplastic so heat sealing was the obvious answer, and better still if the heat is created inside the material instead of melting the outside before it gets to where it is needed. HF equipment manufacturers knew more than anyone else about this thick and had set about meeting this new need. Two U.K. prototype pedal welders have been dated at 1945 and 1946. But although heating a dielectric in an HF field between electrodes was already a successful manageable process for drying and softening plastic pellets for compression moulding actually pressing electrodes against much thinner plastic and producing more intense heating than ever needed previously was a much tougher proposition.

Intense electric stress destroys insulation where it is too fierce and causes flashovers and damaging arcs. With hindsight it is easy to see that the first commercial success of early, pedal operated, welding machines would naturally be in welding the thickest useful materials. These included varieties of PVC coated cloth, rapidly replacing traditional weatherproofed fabrics. Unlike calendered sheeting, cloth supported vinyl material maintained vital thickness even when the welding process was inadvertently overdone, so there was far less danger from accidental flashing between welding tools. These were not elaborate, usually consisting of little more than matched pairs of straight brass bars, seldom longer than 150mm or wider than 10mm. Fishermen’s ‘oilskins’, motorcyclist’s clothing and tarpaulins were early beneficiaries of the new process. The cleverly cut shapes of clothing were necessarily sewn together before the seams were sealed on a welding machine, and ex-sewing machine operators soon learned that stationary piece of brass became as unfriendly to stray fingers as a vibrating needle when it became a live electrode during welding.

By popular request the next models of welding machine inverted the connections to the HF generators so that the upper welding tool then became the ‘live’ electrode, ‘the better to see the devil you know’. The now earthy lower electrode could then be safely enlarged into a useful flat workplate. But the task of welding thin sheeting remained hazardous until it was appreciated that facing the cold plate with a sheet of inert insulating material reduces power required to combat heat losses and provides extra insulation between electrodes, which becomes more important as the welded plastic gets thinner.

The beneficial use of this buffer sheet in plain welding inevitably led many people to the ‘discovery’ of tear-seal welding when material in welds pressed thin enough to lose strength still provided seals between material on each side of the ‘spoiled’ weld which were usefully strong. Here was a way to cut pants to shape and weld them together in one go! It
was undeniable that resulting products looked much better when the severed edges were nicely defined by a sharp edges welding tool but this was technically objectionable because sharp edges intensify electric stress. However, the commercial attractions of the promising tear-seal technique were so strong that this handicap was accepted as a necessary evil. But the flashover menace was now firmly back on the agenda, top of the list of problems to be solved. It remained on the lists for another ten years.

The new products which sheeting manufacturers introduced during the 50’s were noticeably better, cheaper or different than anything seen before. Some were quite suitable for welding, others were not. Today’s HF welders would object to carbon clack or metallic powder in the formulation of a sheeting or the ink printed on it: ignorance of such things caused much chagrin then. But the entrepreneurs pressed on, asking silly questions of the ‘experts, attempting the impossible and succeeding surprisingly often.

Welding machines were now quite practical devices although best results were obtained by very careful users with good tool repair facilities. They were ready customers for larger machines, needing compressed air to work the presses. Too few knew that high pressure air as delivered into tyres is too wet and dirty to pipe into a welder, but everyone was climbing the learning curve.

Welding toolmaking was progressing rapidly. While traditional engineering toolshops were still I bashing and cutting raw metal to new shapes needed for welding, others had seen likeness in the printing process. Printers had enjoyed plenty of time to devise and test the parts they assembled to provide a printing face on the letterpress ‘tools’ which put ink on paper, and they traditional suppliers were overjoyed to find a new and growing market for the specialised products they could sell virtually off-the-shelf for welding tool construction. Accurately made ‘printers’ brass rule, bent to shape and fixed on edge to fiat aluminium plates enabled all sorts of possibilities to be realised at modest cost, and still does. There is little difference in the construction of most tools built today and those fabricated in the late 50’s.

By then HF welding was penetrating old industries and providing some products which could be made no other way. Sizes ranged from key fobs to air-beds, raincoats and plastic ‘quilting’. Little remains of many hundreds of miles of the latter, made with ever thinner PVC sandwiching vinyl foam padding which provided a soft feel and emphasis for its usual ‘chickenwire’ pattern of overall welding. Changing tastes staved off its threat to cover everything touchable, but we have to thank this product for stimulating development of automatic feeder mechanisms gripping sheeting right off-the-roll and precisely advancing it into place under a welding tool, usually in a bridge type press with 7 kw – 15 kw of HF power.

Meanwhile, rainwear manufacturers struggling with early model welders and demand for ever cheaper garments had welcomed the superbly timed launch of the first product of a new company, dedicated to making welders. This was a new 1.5 KW machine, quite able to cope with 0.1 mm sheeting, the thinnest worth using, which tamed the flashover bugbear primarily because it operated at a higher frequency, - selected according to the customer’s area to avoid interfering with regional TV transmissions (see High Frequency Welder Magazine, Issue No. 10 pp. 7) Its electrics were also boldly innovative but out of sight, unlike its ergonomic design and engineered press mechanism, - adjustable to suit tool depth, weight and best welding pressure. It worked like a dream and its effect was sensational. Few customers cared that I might sometime’ become illegal to weld at those frequencies. The payback time was only a few months when everyone needed a Pakamac (a super brand name used as indiscriminately as Hoover’s). Renee Bazi’s Acme No. 1 pointed the way pedal welders had to go and both Redifon and Radyne, the two major competitors, responded very smartly with the introduction of remarkably similar models into the ranges they were already selling.

Two earlier émigrés from Redifon’s HF Heating division had founded Radio Heaters Ltd. Which, under the RADYNE trademark, had grown to become the world’s largest makers of industrial electronic heating equipment. In broad terms, C.E. Tibbs looked after the metal heating applications and E. C. Stanley was responsible for dielectrics, including HF welding. Work on every kind of HF welding application occupied a sizeable department which was accumulating a wonderful fund of experience, unexcelled in the ‘big-stuff’ going into the motors factories to produce car upholstery and trim. It all showed in Eric Stanley’s handbook ‘High Frequency Plastic Sheet Welding’, published in 1960. Amazingly, many welders refused to buy it, objecting that it could not teach them anything about their particular business, that all Radyne customers should a copy gratis, or believed it was just an expensive catalogue of that company’s products. In fact, its 340 pages in hard covers provided a comprehensive review of theory and current practice both large and small,
with diagrams and photographs. Who could blame the author for using his own company’s pictures, they were all exemplary, with the text remarkably clear and apparently unbiased. It never ran to a second edition so existing copies are highly prized, our best record of the remarkable progress the state-of-the-art had made in 15 years.

The first double shuttle trays and automatic rotary indexing tables had proved their worth and, with roll-fed linear feed mechanisms, led the way to faster production, for HF welding was now a manageable process with new equipment serviceable enough to last longer than anyone imagined. All the groundwork had now been done for HF welders to prosper in the booming 60’s.

Despite the publicity ‘radio welding’ was getting in the press and exhibitions, most practitioners found themselves in the business seemingly by pure chance, when they learned it was a process which could help in the manufacture of their existing products, or the best way to produce something they had invented ‘to be made in sheet plastic’. Sheeting suppliers then recommended a welding equipment manufacturer hopeful that the favour would be returned. The dependency on mutual goodwill was probably the greatest spur to improving the welding quality of PVC sheeting on the premise ‘look at the price and feel the width’.

Entrepreneurs who were not intimidated by the capital cost and technology of the heavyweight electronics which make it work discovered a clean fast process capable of converting sheet PVC into first class finished goods with astonishingly low tooling cost. They set about creating new products and, like the lively mac makers for all they were worth.

Welding machines could be sold by the dozen when a new market was developing, but some proved worth far less than others and some never got going, e.g. Nylon (type 6) shirts promised much when found to be weldable: it was not the intending welder’s fault that sales of these garments died in ignominy just when deodorant sales were rocketing. Nevertheless there were plenty of successes, with products that we now take for granted and some that we don’t need anymore.

Entire factories have been kept busy on a single new product line. One such was lightweight welded PVC overshoes, popular with both sexes until affluence brought tall boots and motor cars to keep feet dry. Most cars were then sporting welded Vinyl upholstery, attractive, washable and durable’, but even so, they prompted substantial sales of clear PVC protective covers to proud new owners. Nowadays few drivers are keen to sin on even a single thickness of impermeable plastic. The market life stories of many welded products is rich material for business case studies.

Talent to perceive and safety new needs is not special to the HF welding industry but has certainly given it energy to adapt and grow over the years. Another characteristic is a rugged independent spirit, which probably accounts for the abundance of suppliers to the hundreds of small companies which produce most of the U.K.’s welded products.

The technology of the welding process is just one application of HF dielectric heating, which is closely related to HF induction heating applied to metals. HF power generators for all the processes are much the same except for their operating frequencies, so the engineers who build them know a lot about HF heating in general. Nevertheless, the fascination and prospect for welding were sufficient motivation for the founding of the majority of U.K. welding equipment manufacturing companies, by people who believed they could build a better welder, usually a particular type. If they succeeded they went on to extend their product range to compete on a broader front, not excluding induction heating!

A new type of welding tool was developed in the 60’s which enables a stiff sandwich of a variety of materials to be welded and/or bonded together and then, in a succeeding follow-through stroke, cut around the profile by a close fitting knife requiring very high pressure. Cutting presses had been used in leather goods and clothing industries for many years and the latest hydraulic models with sophisticated controls were ready and suitable for applying the two stage motions and pressures for this type of tooling. Cooperation between HF and cutting press engineers thus produced a new type of ‘cut-weld’ machine and added new names to the list of suppliers to the industry.

A completely different type of tooling was development in the 70’s. This separates the top surface of welded material from the upper heating electrode with a thick membrane of moulded silicone rubber which impresses the workpiece to reproduce decorative details and texture of flat master models with remarkable fidelity. This ‘flow-moulding’ technique is best exploited using machines built for the purpose, but these were not so radically different from ‘ordinary’ welders.
Both of these techniques found immediate use in shoe manufacture: flow-moulding of fancy uppers and cut-welding of insoles. Of course new applications for old techniques are discovered all the time, not least in plain and tear-seal welding.

The process at the business edge of ordinary welding tools remains much the same except that tool temperature are maintained steadier, where possible, in the cause of quality control. The threat of damage from accidental arcing has receded almost out of sight in the face of increasingly successful countermeasures.

When it seemed impossible to prevent occasional arcs the problem resolved into two parts, early detection and damage limitation. Detection methods tested included radios sensitive to the crackle of the tiny lightning striking the arcs. (Engineers were seen listening to miniature war-surplus MRC1 receivers as intently as the French Resistance they were designed for). Adjustable overload trips worked if an arc caused power to increase, sometimes they didn’t. Best results were obtained by using the direct current path through the plasma of an arc between the welding electrodes to operate a relay which opened the HF generators overload trip circuit to cut off its power supply. Such arc-limiters became the norm and were easily fitted to earlier welders, but unwanted damage still occurred in the split second electromechanical devices required to operate. Quite fancy electronic gadgetry was needed to ‘disable’ an HF generator instantly, and it became available in expensive ‘bolt-on’ goodies.

In 1968/69 a new machine from a new manufacturer again shook up ideas on controlling the arcing menace. Its generator was disabled between each and every heating cycle, by simply preventing its oscillator valve from conducting (which it is very ready to do, at high frequency). The technique is as old as HF wireless telegraphy but was a novelty when applied to plastic welding, requiring only cunning, but relatively inexpensive, extra circuitry to detect an arc and clamp a blocking bias voltage on the oscillator valve’s grid electrode somewhat earlier than programmed by the heating timer. The rest as they say, is history: it became a ‘standard practice’ for there is no quicker way to terminate HF power. Today, modern electronics enable unexpected rise and falls of power levels to be detected as well as change in resistance of work material so that detection of imminence can prevent an arc occurring. Arc Anticipators are with us now.

Generators had improved in any case, discarding bulky banks of weirdly luminous rectifier tubes or their soulless alternatives, selenium rectifiers with their stink of protest at old age or misfortune, (which put much strain on interpersonal relationships). Solid state devices have not yet replaced oscillator valves, but even these now hide their lights within sturdy ceramics. No matter, a generator is just a converter of power to heat the plastic where the work is done and both welder users and their suppliers had switched most attention to finding ways of doing it better.

HF welding leaves scope for ingenuity in methods of presenting work for welding and this was seen in the variety of arrangements tested as new products were developed. The most teasing problems concerned the correct positioning of ancillary components necessarily included with work materials which are then welded around them. Gravity could hold substantial board stiffeners in place for welded padded seating and baby carriage panels but was no help in holding rubber bands in baby pants, made in millions, eventually at prices only attainable with special purpose machines. Generally similar problems beset welders tackling the large and diverse markets for book covers. Simple methods of locating their board stiffeners work well enough to be economical for short runs of loose leaf ring binders, but more sophistication is required for more complicated work or high volume production.

European manufacturers with larger markets were first to take serious advantage of special purpose machinery unwinding rolls of PVC and inserting magazine-fed stiffening boards between the webs as they were carried into a welding press. Most other additional operations of printing, stamping, punching, pocket welding and final separation can now be included ‘in line’. An automatic production line need not be straight, as rotary indexing tables also have much to offer, possibly allowing most scope for ‘pick and place’ robotic machines to be stationed where most convenient. We have already reached the point where an automated production line can be assembled from standardised units where the welding station, with appropriate size of press and generator, is just one of those units.

Nevertheless there is still need for both general purpose and special welding machines for operations which demand special methods. Special methods were needed for producing blood transfusion sets and the subsequent development of markets for HF welded disposable medical products such as colostomy bags has been astounding. The particular demands of these markets not only merit special machinery to manufacture the products but justify dedicated buildings with controlled purified atmospheres to house them. Similar investment by manufacturers of PVC to stringent medical
specifications has been correspondingly rewarded. A list of current application of HF welding now includes hundreds of diverse products and continues to grow. It is hard to predict how and where new markets appear but they surely do and this industry has shown itself notably willing to respond to opportunity. Inevitably, this account of seemingly significant events seen by one guy’s eyes must miss much that is important to many people engaged in plastic welding. Mergers, acquisitions, takeovers, buy-outs, disposals, all these things shape our lives and this industry has seen them all, too many to chronicle here even if we knew the facts.

However, there is one significant event in recent history that must be mentioned. In December 1986 a couple of dozen HF welders who believe most luck comes to those who try hardest arranged a meeting which discussed setting up an organisation to represent and advance the interests of all U.K. welders. The consensus of that meeting was that it would meet a real need but much work was needed to enthuse several hundred companies who comprise the industry to support the idea with money and forbearance until the (unpaid) effort entailed could bear fruit. The first tangible result was a much larger meeting in Coventry in June 1987 which endorsed the principle, pledged support, and elected a Management Committee here and then. The rest really is history, now properly recorded in the minutes of meetings of that committee and the magazine of the Federation of High Frequency Welders.
APPENDIX B

MATERIAL NAMES AND ABBREVIATIONS

The chemical names of the various types of polymers are often quite long and complicated, and therefore in the industry simple abbreviations are used. The following tables give the abbreviations for more “popular” Plastics compounds. For each abbreviation in the commonly used chemical name is given, plus representative examples of Trade Names.

NOTE:

(a) Some suppliers use the same trade name for several different materials for example Dow use the name Styron, and Hoechst Hostyren for both polystyrene and high impact polystyrene.

(b) Some material suppliers use trade names which clearly indicate the material type, e.g. Beetle Nylon 6, Beetle Urea (BIP Chemicals) or Bakelite Phenolic.

(c) For a more comprehensive lists of abbreviations the British Standard 3502 part 1: 1978 should be consulted.
## Thermoplastics

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Chemical Name</th>
<th>Trade Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS</td>
<td>Acrylonitrile butadiene styrene terpolymer</td>
<td>Novodor, Cycolac, Lustran, Terluran</td>
</tr>
<tr>
<td>ACETAL</td>
<td>Polyoxymethylene (polyformaldehyde)</td>
<td>Delrin, Kermel, Hostaform, Ultraform</td>
</tr>
<tr>
<td>ACRYLIC</td>
<td>Polymethylmethacrylate</td>
<td>Diakon, Lucite, Plexiglas</td>
</tr>
<tr>
<td>CA</td>
<td>Cellulose acetate</td>
<td>Tenite, Dextol</td>
</tr>
<tr>
<td>CAB</td>
<td>Cellulose acetate butyrate</td>
<td>Tenite B, Cellor B</td>
</tr>
<tr>
<td>EVA</td>
<td>Ethylene vinylacetate copolymer</td>
<td>Evathane</td>
</tr>
<tr>
<td>HDPE</td>
<td>High density polyethylene</td>
<td>Lupolen, Rigidex, Vastolen A</td>
</tr>
<tr>
<td>HIPS</td>
<td>High impact polystyrene</td>
<td>Hestyren, Styron, Lustrex, Lacroline</td>
</tr>
<tr>
<td>LDPE</td>
<td>Low density polyethylene</td>
<td>Alcyathene, Lupolen, Hosteien, Stamylan</td>
</tr>
<tr>
<td>PA6</td>
<td>Type 6 Nylon, (polyamide)</td>
<td>Akulon M &amp; K, Ultramid, Maranly B, Gilson</td>
</tr>
<tr>
<td>PA66</td>
<td>Type 66 Nylon, (polyamide)</td>
<td>Akulon S, Ultramid A, Maranly A, Xytel 66</td>
</tr>
<tr>
<td>PA11</td>
<td>Type 11 Nylon, (polyamide)</td>
<td>Rilsan B</td>
</tr>
<tr>
<td>PA12</td>
<td>Type 12 Nylon, (polyamide)</td>
<td>Grilamid, Vostamid, Rilsan A</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Chemical Name</th>
<th>Trade Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>PBTP (PBT)</td>
<td>Polybutylene Terephthalate (thermoplastic polyester)</td>
<td>Viatex, Ultradur B, Pocan B, Celanex</td>
</tr>
<tr>
<td>PC</td>
<td>Polycarbonate</td>
<td>Makrolon, Lexan, Calibre</td>
</tr>
<tr>
<td>PET</td>
<td>Polyester terephthalate (thermoplastic polyester)</td>
<td>Amite A</td>
</tr>
<tr>
<td>PMMA</td>
<td>Polymethylmethacrylate (acrylic)</td>
<td>Diakon, Tucite, Plexiglas, (Perspex)</td>
</tr>
<tr>
<td>POM</td>
<td>Polyoxymethylene (Acetal)</td>
<td>Delrin, Kermel, Hostaform, Ultraform</td>
</tr>
<tr>
<td>PPO (PPE)</td>
<td>Polyphenylene oxide (ether) (modified with polyphenylene)</td>
<td>Noryl, Lurayn</td>
</tr>
<tr>
<td>PP</td>
<td>Polypropylene</td>
<td>Novolen, Propathene, Stamylan P</td>
</tr>
<tr>
<td>PS</td>
<td>Polystyrene</td>
<td>Styron, Polystyrol, Hostyren, Lustrex</td>
</tr>
<tr>
<td>PTFE</td>
<td>Polytetrafluoroethylene</td>
<td>Fluon, Teflon, Hostaflon</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl chloride (plasticised flexible)</td>
<td>Hyvin, Vinoflex, Vasolet, Lacryl</td>
</tr>
<tr>
<td>SAN</td>
<td>Styrene-acrylonitrile copolymer</td>
<td>Luran, Tyril</td>
</tr>
<tr>
<td>UPVC</td>
<td>Unplasticised polyvinylchloride (rigid)</td>
<td>Hostalit, Welvloc, Geon, Hyvin, Veslollit</td>
</tr>
</tbody>
</table>

## Thermosets

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Chemical Name</th>
<th>Trade Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMC</td>
<td>Dough Moulding Compound (thermoseet Polyester)</td>
<td>Freewax, Polycure, Premiglas</td>
</tr>
<tr>
<td>EPOXY</td>
<td>Epoxy moulding compound</td>
<td>Araldite</td>
</tr>
<tr>
<td>MF</td>
<td>Metalline formaldehyde (alcohol)</td>
<td>Melmix, Ultraplas</td>
</tr>
<tr>
<td>PF</td>
<td>Phenolic formaldehyde (phenolic)</td>
<td>Trolitan, Bakelite</td>
</tr>
<tr>
<td>SMC</td>
<td>Sheet Moulding Compound (thermoseet polyester)</td>
<td>Flonam, Premiglas</td>
</tr>
<tr>
<td>UF</td>
<td>Urea formaldehyde (alcohol)</td>
<td>Poliolat, Bettle urea</td>
</tr>
</tbody>
</table>
GLOSSARY OF TERMS USED IN THE HF WELDING INDUSTRY

Anode Current
The electrical current flowing from the anode(s) of the generator’s output valve(s). This current gives an indication of the output power of the generator and is dependant on the setting of the output power control (usually a variable capacitor) which resonates the generator’s output tuned circuit. The current is also dependent on the loading effect of the electrode and tooling on the tuned circuit.

Appliqué an Welding
Welding process where a piece of material is cut out and welded to the surface of another to provide ornamental effect.

Arcing
An electrical “flashover” which occurs if the welding machine’s electrodes (i.e. the platen at HF potential and the worktable at zero HF potential) come too close together or touch. Arcing can damage both the generator and the tooling, therefore arcing anticipator circuits are usually incorporated in welding machines to cut off the HF power before damage is caused.

Barrier Material (Buffer Material)
A thin sheet of dielectric that is placed between the work material and the welding machine’s lower platen to reduce heat loss, and in tear-seal welding to prevent damage to the tooling. Any material used as a barrier must be able to be repeatedly used in the electric field without being affected.

Blind effects onto Embossing
A technique which can be incorporated into the welding process to place lettering, logos or decorative the welded items.

Calendered and PVC
PVC which has been finished by passing between heated metal rollers which impart the required finish thickness of the product.

Cooling Time
The time between the end of the Welding Time and the lifting of the tooling from the workpiece.

Dielectric material
Any, solid, liquid or gas which can sustain an electric field, hence an insulator. When a thermoplastic is HF welded, it acts as a dielectric between the electrodes.

Electrode
A conductor through which an electric current enters or leaves an electrolyte. In HF welding, the term electrodes refers to the platen and the worktable. In this case, the electrolyte is the thermoplastic being welded.

Frequency
The rate of repetition of a periodic disturbance, measured in hertz (Hz) (cycles per second). In High Frequency welding, the most commonly used frequency for welding is 27.12 MHz

HF
The abbreviation for High Frequency, the range of Radio Frequencies between 3,000 and 30,000 kHz or 3 and 30 MHz.
Plain Welding
The welding of two or more layers of thermoplastic material by applying HF power to heat and thereby fuse the inner surfaces.

Platen
The upper electrode of a welding machine.

Polyolefins
Fibre of film made from a linear polymer obtained from an olefin especially ethylene (giving polyethylene) or propylene (giving polypropylene).

Power Control
A device, usually a variable resistor or capacitor located in the power output stage of a generator, which enables the HF output level of a welding machine to be adjusted.

Pressure
The force applied to the workpiece materials to compress them during the welding cycle.

PVC
Polyvinyl chloride – The best known and most widely used of the vinyl plastics.

RF
Radio Frequency – The spectrum of frequencies between 10 kHz and 3 GHz. Within this spectrum, frequencies are split into Low Frequency (LF), Medium Frequency (MF), High Frequency (HF), Very High Frequency (VHF) etc. Note that RF is the generic abbreviation for radio frequencies and is sometimes misleadingly used instead of HF.

Stick Weld
A weld where the two surfaces to be joined fail to become perfectly homogenous. The weld often appears to be normal, and a special technique of static loading is necessary to ascertain whether the weld is satisfactory.

Tear-Seal Welding
The dual process of simultaneously welding and cutting a material. This is achieved by incorporating a cutting edge adjacent to the welding edge.

Thermoplastic
Becoming plastic on being heated. Specifically any resin which can be melted by heat and then cooled, the process being repeatable any number of times without appreciable change in properties.

Tuned Circuit
An arrangement of reactive components (inductors and capacitors), connected in series of parallel to offer a low or high impedance respectively, to an alternating current at the resonant frequency. HF generators use a series tuned circuit to match the output of valve(s) to the impedance of the welding head components. This matching enables the maximum transfer of HF power.

Welding Time
The length of time that the HF power is applied to, and creates heat in the workpiece.