

THERMATOOL CORP.

HIGH FREQUENCY WELDING

OF

ALUMINUM

H.N. Udall (Deceased)
Robert K. Nichols, P.E.
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HIGH FREQUENCY WELDING OF ALUMINUM

By H.N. Udall and R. K. Nichols, PE

Thermatool Corp.

Aluminum, as well as many other non-ferrous materials, has been successfully welded by the High Frequency method for many years. While the process varies only slightly from the method used to weld carbon steel, attention to the differences is necessary to ensure a proper weld.

THE TUBE MAKING PROCESS

Welded pipe and tube is made by longitudinally forming flat metal strip into a nearly complete tube and then welding the edges together. To do this, the metal strip is fed into a forming mill that shapes the strip. As the strip passes through the work coil, current is induced to flow in the strip, mostly in the edges (Fig 1.). The metal's resistance to the flow of electricity causes the edges to heat very rapidly to the melting point. While the edges are still molten, they are forged together by the weld rolls, extruding the oxidized molten metal and bonding the clean metal below it to complete the welding process.

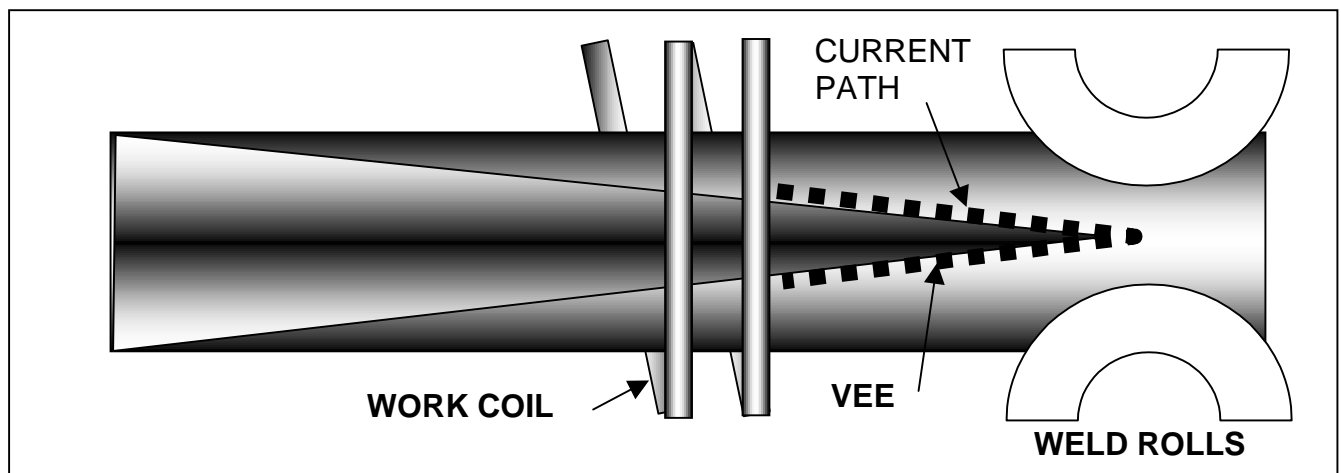


Fig. 1 Vee Schematic and Current Flow

THE HIGH FREQUENCY WELDING PROCESS

There are two phenomena that are unique to High Frequency current flow. The first is called the "skin effect" and describes the tendency of HF current to flow in a very shallow skin on the surface of the metal. The higher the frequency, the shallower the skin of current penetration. The other phenomenon is called the proximity effect and describes the way two opposite HF currents flowing near each other will concentrate the current on adjacent edges of the conductors (Fig 2.).

Because of these two effects, most of the HF current will flow in a shallow skin on the inside edges of the vee formed by the strip. The closer the edges are together (i.e., the narrower the vee) the greater is the contribution of the proximity effect. Since more power will be concentrated in the strip edges, they will heat faster. For carbon steels, a vee angle of 2-5

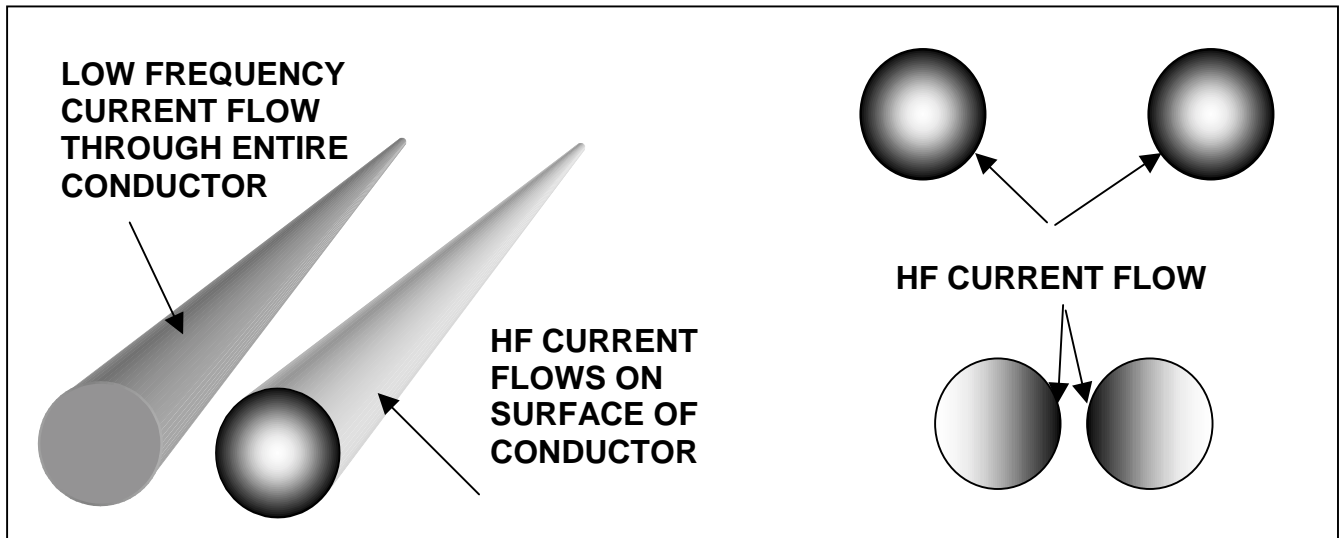


Fig. 2 Skin and Proximity Effects

degrees is recommended. a narrower vee will be more power efficient but may create weld defects and a wider vee can become too inefficient. To minimize the amount of current flowing around the back of the tube, a ferrite impeder is placed inside of the tube to be welded where it concentrates the magnetic flux lines into the vee. The melting will be limited to about 2/3 of the reference (penetration) depth for the frequency being employed. The reference depth is calculated using the following formula:

$$d = 3160 \sqrt{R / mf}$$

Where:

d = Reference depth in inches

R = Resistivity in ohm-inches

m = magnetic permeability

f = Frequency

For aluminum, the reference depth at 450 KHz is approximately .005". This figure doubles when aluminum reaches 600°C. Aluminum can be welded at any convenient frequency based on the desired line speed. For low mill speeds, say below 50 feet per minute, frequencies as low as 95 KHz have been used. When the mill speed exceeds about 100 fpm, frequencies in the 400 KHz range will perform better. for welding very thin wall materials (less than .015"), frequencies as high as 800 KHz. have been used at mill speeds over 500 fpm.

WELDED AREA RELATIONSHIPS USING VACUUM TUBE TECHNOLOGY

The drawing in Fig 3. shows the weld area relationships necessary for efficient operation and good welds using a vacuum tube welder. The impeder should be placed just past the weld roll centerline, the coil ID should be about 1/4" larger than the tube OD, the length of the coil should be equal to the coil ID, and the distance between the coil and the weld point should be equal to the coil length. For very thin walls, an impeder may not be necessary.

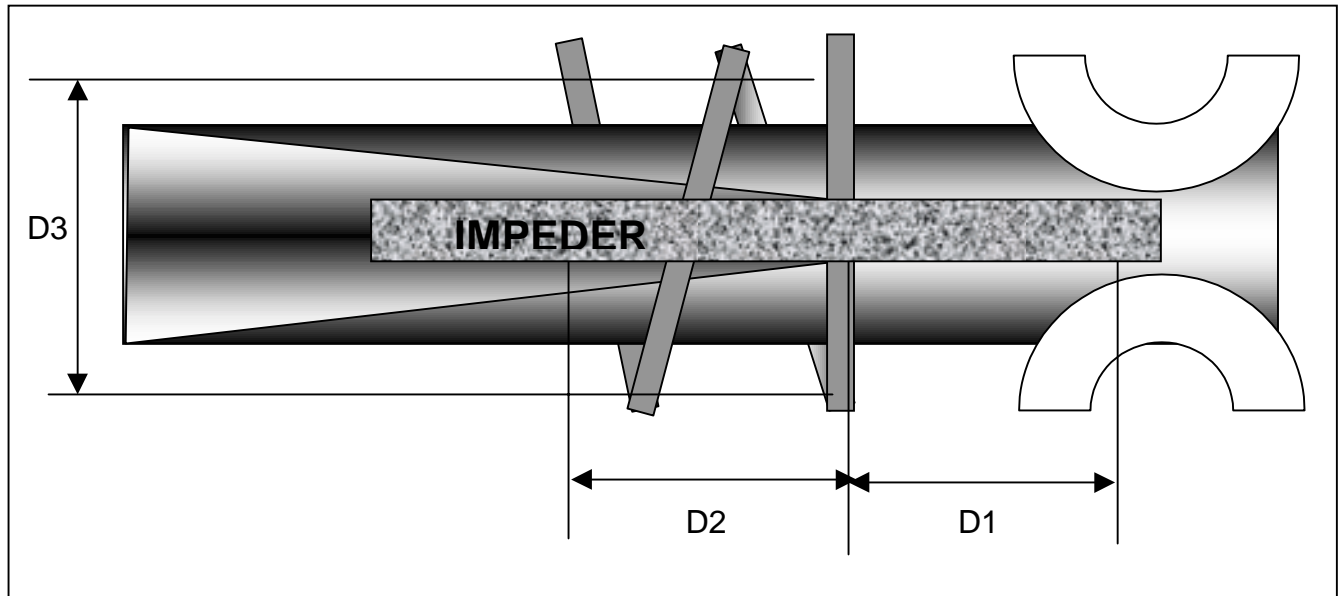


Fig 3. Weld Area Component Relationships

Failure to maintain these relationships will reduce the overall efficiency of the welding operation and may promote weld defects.

WELDED AREA RELATIONSHIPS USING SOLID STATE TECHNOLOGY

When using a solid state welder that is supplied with a current-fed inverter, there are a few minor changes to the weld area component relationships. First, the weld coils will most likely be banded rather than plain coiled copper tube. Second, the coils will probably be longer than the ones used with a vacuum tube welder. Third, the impeder must be made longer. Typically, the impeder must be twice as long as the coil (D2 in Fig 3) plus two vee lengths (D1 in Fig3) . Lastly, some users have reported that the weld bead can be made extremely smooth by pulling the impeder back so that the end of the impeder is ¼"-1/2" from the apex of the vee. Moving the impeder back will have a slight negative impact on the welders operating efficiency, however the benefits may outweigh the cost.

Additionally, the amount of spume ejected from the apex is much reduced when the impeder is moved back. This is because the intense magnetic field created at the end of the impeder does not line up with the molten metal in the apex of the vee. With the reduction of the magnetic field in the area of the molten metal, there is less force to eject the liquidus. However, because less metal is ejected as spume, it could result in a larger weld bead.

VEE LENTH AND WELD ROLL SIZE

If the coil is placed too close to the weld rolls, some power is lost as current is induced into the roll. This causes the rolls to heat up and may result in damage or premature failure of steel rolls. Placing the coil too far away from the weld rolls causes the length of the vee to grow longer (Fig 4.), requiring more metal to be heated up which takes more power. It also allows the heat generated to flow into the body of the strip for a longer period of time. In small diameter tubes, the vee length may be longer than the edges of circumference and the current will flow mostly around the tube. This may rob the edges of sufficient heat and result in cold welds or no welds.

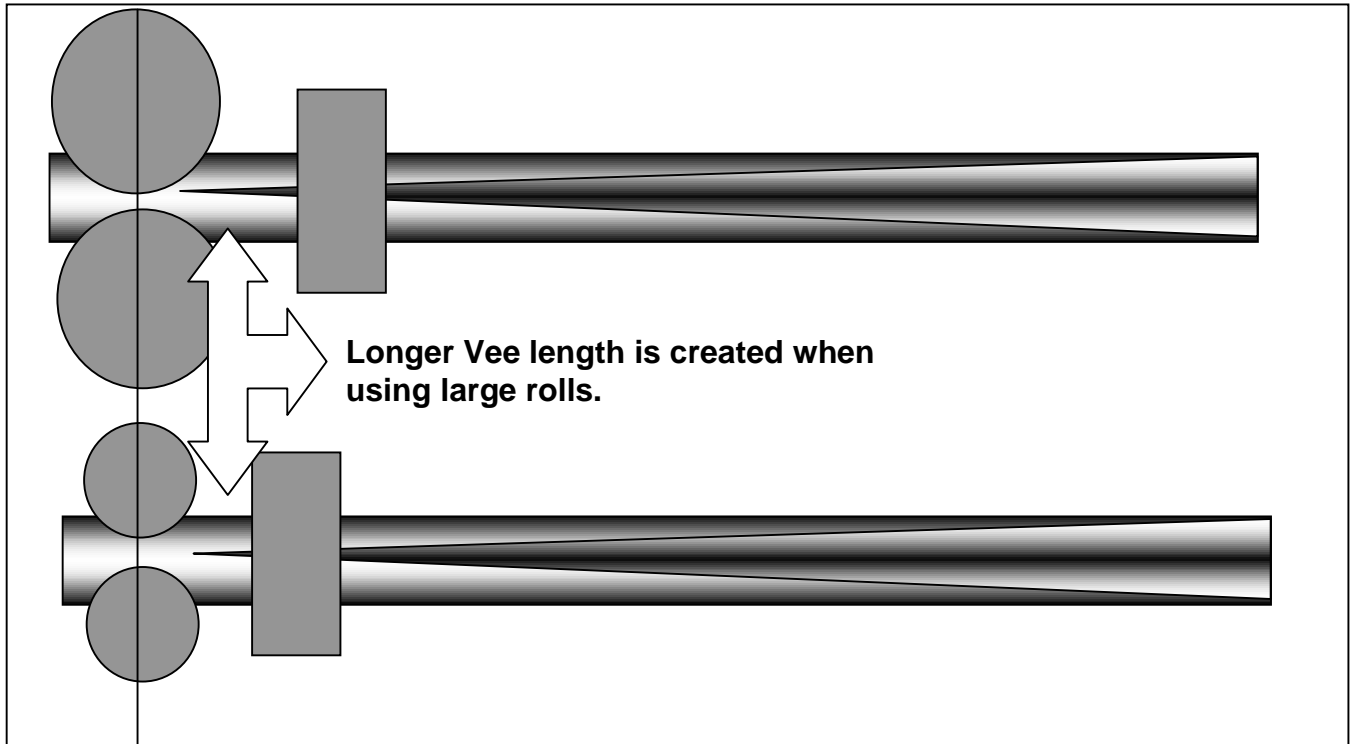


Fig 4. Relationship Between Roll Size and Vee Length

RECOMMENDED MAXIMUM ROLL SIZES FOR SPECIFIC TUBE SIZES

Pipe or Tube OD: <1" 1.5" 2.0" 2.5" OVER 3"

Roll Flange Dia: 2.5" 3.25" 4.0" 5.75" as Req'd

HF WELDING OF ALUMINUM

The HF vee angle for aluminum is recommended to be between 5-7 degrees. This means that at a point 2 inches upstream from the weld point, the vee opening should be between .200" and .300" (Fig 5.).

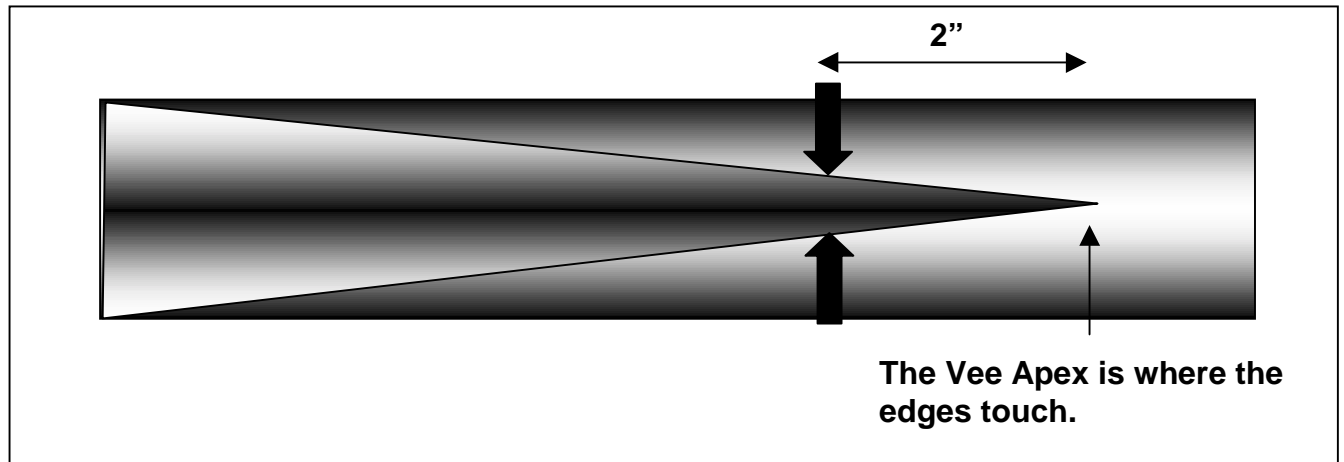


Fig 5. Vee Angles and Dimensions

VEE ANGLE FOR A VEE WIDTH 2" FROM WELD POINT

Vee Width:	.100	.125	.150	.175	.200	.225	.250	.275	.300
Vee Angle:	2.9	3.6	4.3	5.0	5.7	6.4	7.1	7.9	8.6

A narrow vee angle has been observed to create a weld defect called Weld Apex Instability (sometimes called “Blipping”). This defect is caused by a molten meniscus of metal oxides wedged into the apex of the vee (Fig 6.). This “bag” of metal grows to a point where surface tension can no longer support it and it ruptures. Electromagnetic forces then eject the spume. When the molten metal is ejected, there is nothing left in the vee to weld and a cold weld results. It may also suck in some of the molten oxides causing an oxide entrapment. This is a periodic defect that can appear in varying degrees of significance. To minimize the effect, widen the vee. This will reduce the size to which the “bag” can grow before it ruptures.

Since magnesium seems to increase the viscosity of the molten aluminum, it may also be helpful to avoid alloys which are high in magnesium.

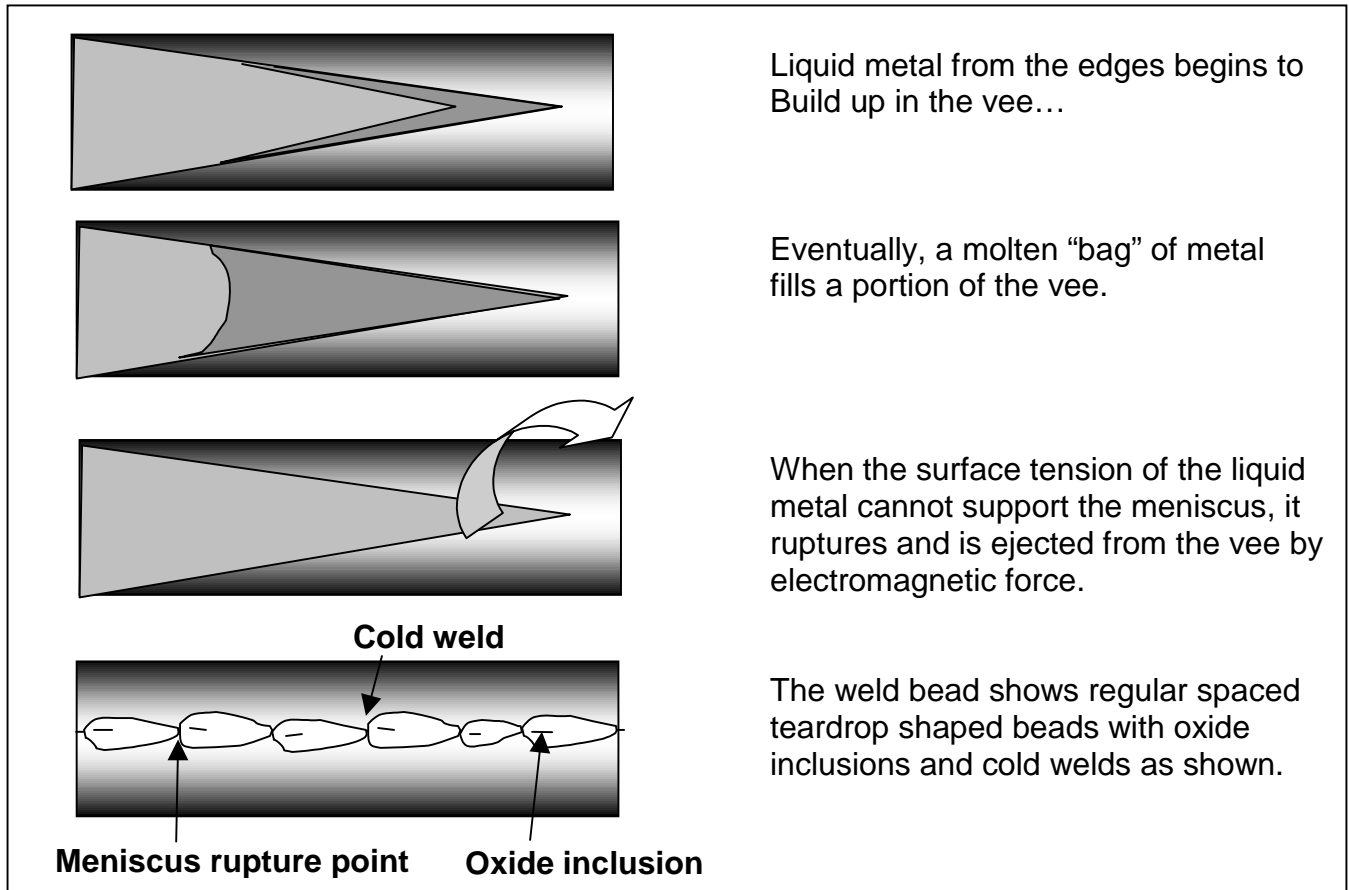


Fig 6. Weld Area Instability Defect

When welding aluminum, it has been found that smaller weld rolls are preferable. Small weld rolls made of bronze or ceramic allow the coil to be moved closer to the apex thus minimizing the vee length. Non-ferrous rolls will not heat up due to the proximity of the coil thus minimizing necessary cooling.

Many applications for aluminum tubing require a smooth ID but because of the small size of the tube, the inside bead cannot be scarfed. To minimize the bead, operate at the highest frequency possible which will minimize the amount of strip melted. Also, ensure that the strip edges are entering the coil with proper registration, that is, flat and parallel. If they enter the coil in the peaked condition, the ID will overheat due to the proximity effect. This will produce more molten metal on the ID (Fig 7.).

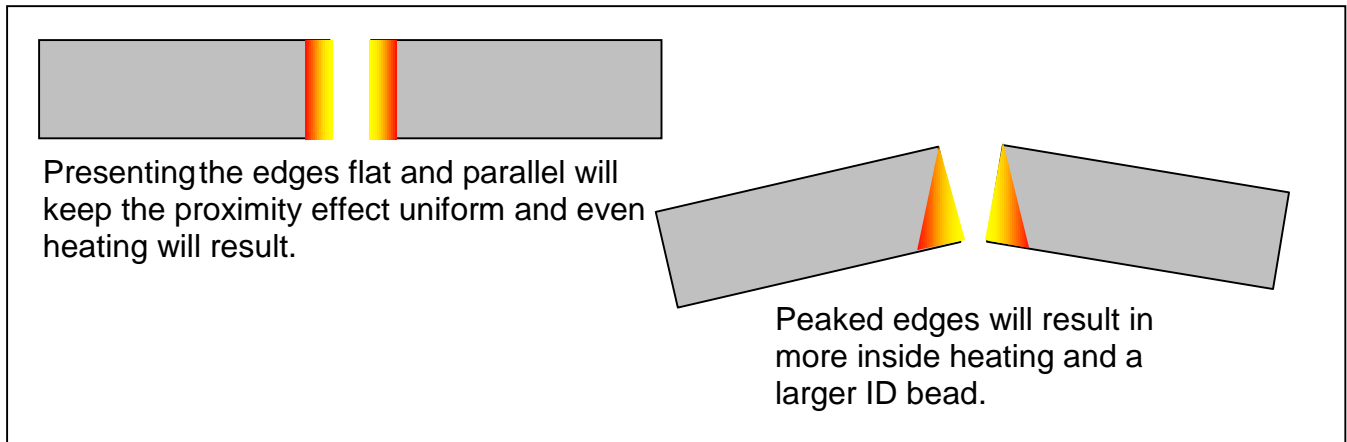


Fig 7. Edge Registration

To smooth the ID bead profile when using a vacuum tube welder, the “ripple” in the DC current must be reduced. Most HF welders come equipped with a “B+ filter” to minimize this ripple, however, extra filters can be installed to further reduce the effect. The new solid state welders produce much less ripple than their vacuum tube predecessors and produce a very smooth bead without extra filtering. In cases where an extremely smooth bead is necessary, the extra filters can reduce ripple to less than .2%.

Running at the highest power level possible will also help reduce the ripple on vacuum tube welders. This coincides with the recommendation that aluminum be welded at a minimum speed of 70 feet per minute to minimize the loss of heat from the strip edges just prior to entering the weld rolls. Faster line speeds only serve to improve the efficiency of the welding process.

Mill coolant, if used at all, should be kept clean and applied sparingly around the weld area. Coolant in the weld area will cool the strip edges very rapidly so if you must use it, direct the coolant flow to the back side of the rolls and keep the vee dry as possible. Many mills weld without coolant at 300+ fpm with no unusual tooling wear. Obviously, if the product is to be painted or used decoratively, surface finish dictates the use of some coolant.

Most aluminum alloys can be welded, and especially pure aluminum. However, the very soft strip can be difficult to control in forming. Conversely, the stiffer alloys form better but the resulting weld line is softer than the tube body. To compensate for this, some thickening of the weld area may be necessary.

Because of the softness of the aluminum relative to the steel in the stands and rolls, edge damage is always a problem. Deep nicks and scratches can easily cause a weld defect and slivers adhering to the edges will cause pre-arcing. Extreme care is warranted in handling the coiled strip and attention to roll condition and alignment is critical.

Because of the spume ejected by the welding process, it is generally wise to provide some method of fume/dust control in the welder area.

SUMMARY

Welding of aluminum is best accomplished by the following:

- 1) Use a vee angle of 5-7 degrees.
- 2) Use the smallest weld rolls possible to place the coil as near to the weld point as possible.
- 3) Use little or no coolant in the weld area.
- 4) Run at speeds in excess of 70 feet per minute.
- 5) Run at highest power levels possible to minimize ripple on vacuum tube welders.
- 6) Run at a frequency consistent with mill speed (400-750 Khz is preferred).
- 7) Use the appropriate impeder for the tube size if required.
- 8) To minimize ID bead:
 - a) Present strip edges flat and parallel.
 - b) Use extra B+ filter on vacuum tube welders or
 - c) Use a solid state welder
- 9) Pay close attention to strip edge condition.
- 10) Use a properly sized dust / fume collection system.