THERMATOOL

WELDING AND HEATING SYSTEMS

COMMON HF WELDING DEFECTS

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High Frequency Welding is undoubtedly the fastest and most efficient method of making pipe and tube. However, it can also present the operator with a bewildering variety of weld defects. It is the object of this paper to present 9 of the most common defects, their causes and how they can be prevented.

A Review of the HF Process

In the HF process, strip is fed into a forming mill, shaped into a cylinder and passed through an induction coil or under contacts (FIG 1). The magnetic field around induction coil causes current to flow on the edges of the strip. The edges, in turn, heat up due to resistance to the flow of current. The hot edges are forged together in the weld rolls and a weld is achieved. The HF weld is a true forge weld in that no filler metal is added and, if done properly, no molten or oxidized metal is left on the bond plane. FIG 2 shows that all of the liquidus and metal oxides are squeezed out of the weld as the edges pass between the weld rolls.

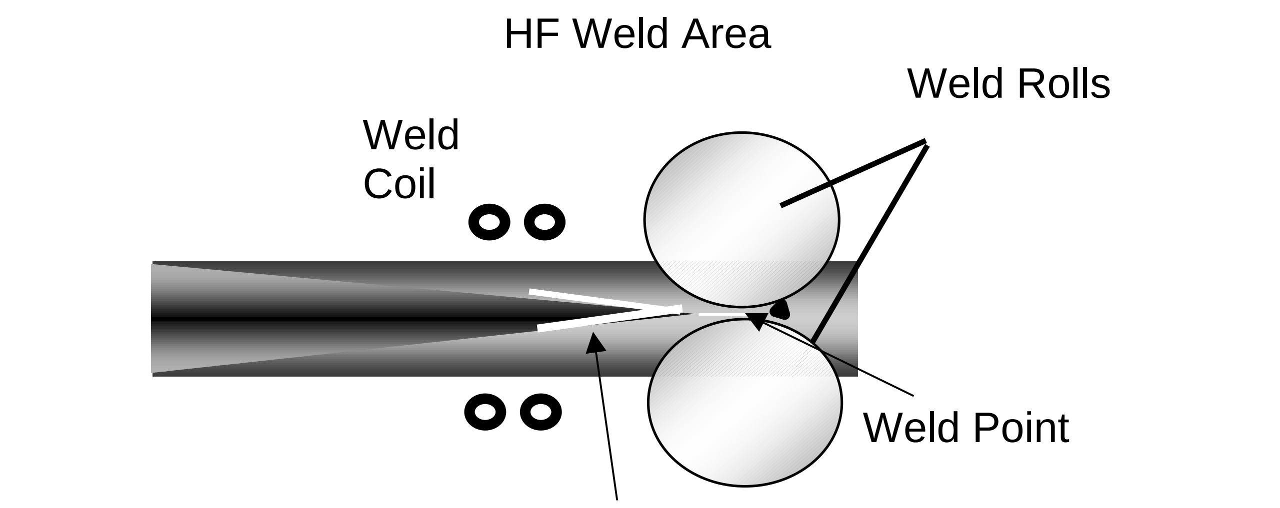


Fig 1

If cut, polished, etched and examined under a metallurgical microscope, the normal HF weld area will appear as represented in FIG 3.

Note that the Heat Affected Zone (HAZ) is shaped like an hourglass. This is because the heat generated by the HF current enters the strip edge from the top and the side of the edge. The HAZ is usually darker than the parent metal because carbon in the steel diffuses toward the hot edges during the welding process and becomes trapped on the edge when the weld cools. The bond plane is usually light colored because it is very low in carbon. The carbon on the very edges oxidizes to CO and CO_2, leaving the iron without carbon to darken it. The flow lines are areas of

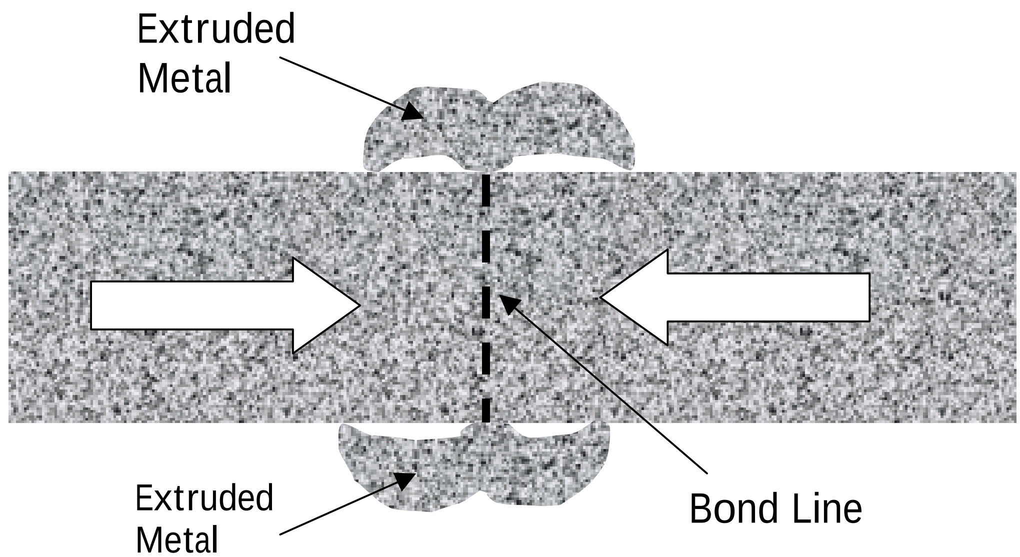


Fig 2

high carbon which were rolled into flat, discontinuous planes when the steel was rolled into strip. Their angle can be used to evaluate the degree of upset done during the welding operation.

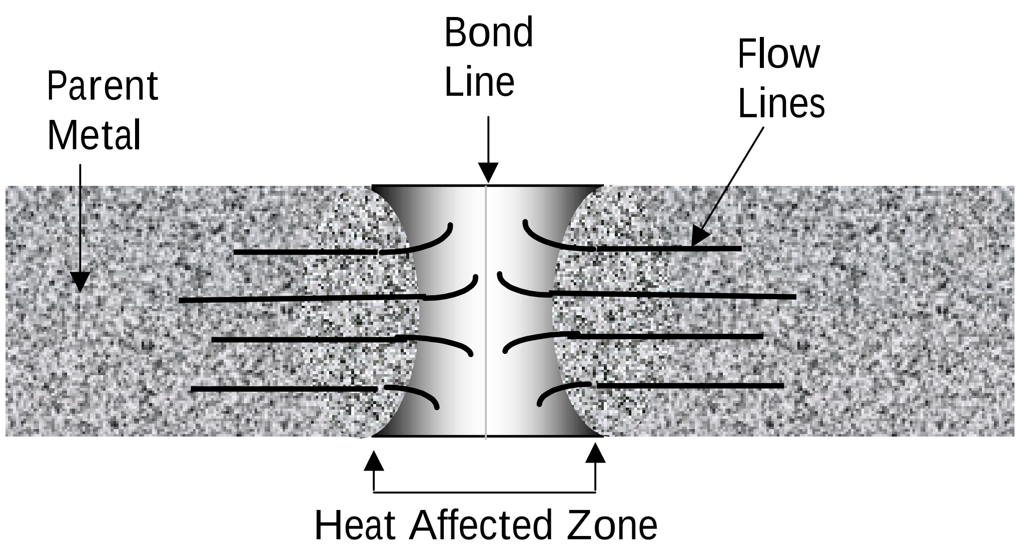


Fig 3

Common HF Weld Defects

There are many types and variations of HF welding defects and each one is known by many different names around the industry. Regrettably, there is no common jargon with which everyone will agree so the following defect names are followed by another common name for the same defect. This list is not exhaustive but does cover the most common defects:

1. Entrapments (black penetrators)
2. Pre-arcs (white penetrators)
3. Lack of Fusion (open seam)
4. Lack of Fusion on edges (puckers)
5. Lack of Fusion in center (cold center)
6. Paste Weld (cold weld)
7. Cast Weld (brittle weld)
8. Porosity (pin holes)
9. Stitching

Rather than try to provide actual photographs of each type of defect, an idealized sketch is provided. This will allow for better definition of the key characteristics and not confuse the issue by showing a defect that may be specific to only one set of welding parameters. Defects are illustrated, as they would appear on the edges of a weld that was broken open in a crush test.

Entrapments (Black Penetrators)

As the name implies, this type of defect is usually a metal oxide that has been trapped on the bond plane instead of being squeezed out with the molten metal. These oxides are formed on the surface of the molten metal edges in the vee. In the vee, if the approach velocity of the strip edges is less that the melt rate, i.e., the edges are melting faster than they are being squeezed, a pocket forms (FIG 4) behind the vee apex which will contain both molten metal and metal oxides. The normal squeeze out does not completely remove the larger than normal liquid volume and an entrapment results (FIG 5)

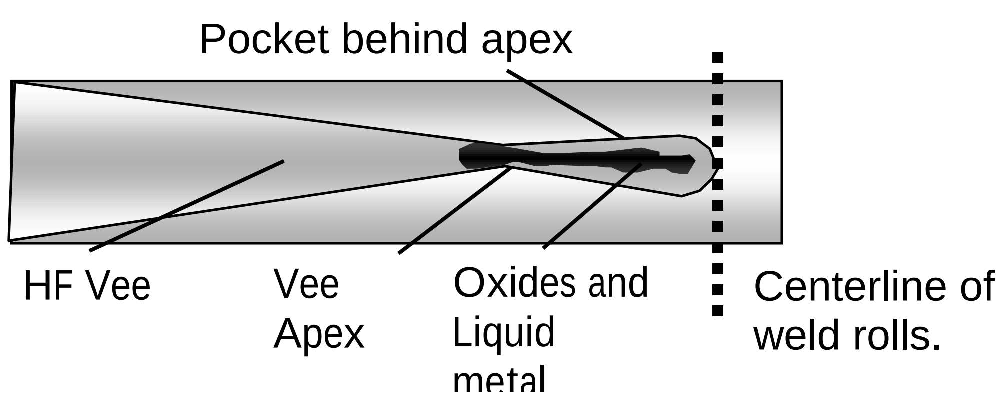


Fig 4.

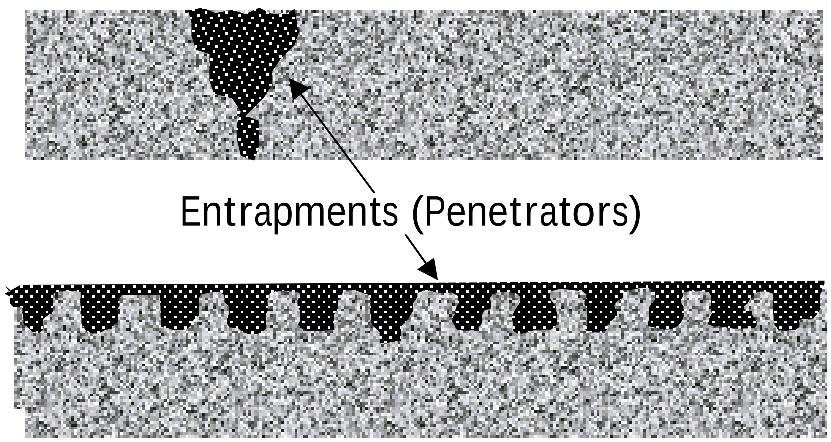


Fig 5

The entrapment is readily observable when the weld is broken open. The surface of the entrapment is generally a dark color and fairly flat in comparison to the rather woody surface of the weld line. They can occur individually or in strings as shown in FIG 5. It has been observed that the incidence of entrapments is increased when the vee is narrow, e.g., less than 4 degrees or when the ratio of manganese to silicon in the strip is less than 8:1. The effect of Mn/Si ratio is difficult to consistently reproduce suggesting that other factors may be involved.

Prevention of Entrapments

1. Maintain a 4-6 degree vee angle.
2. Maintain a stable vee length with proper tooling and mill set-up.
3. Maintain the lowest welding temperature possible that achieves a sound weld.
4. Avoid steel chemistries that have a Mn/Si ratio of less than 8:1

Pre-Arcs (White Penetrators)

The use of the term “Penetrator” is inappropriate for this type of defect because nothing is actually trapped on the bond plane. It is a very short lack of fusion caused by a pre-arc. A pre-arc occurs when the HF current jumps across the vee ahead of the vee apex, usually as a result of a sliver or bit of scale falling across the vee. The short-circuit diverts the current momentarily, robbing the vee of heat (FIG 6).

The very short duration of the diverted current leaves only a short defect, often no longer than the wall thickness. It is easily observed when the weld is broken open and has a flat, shiny surface surrounded by the woody fracture of the rest of the weld area (FIG 7).

It is possible with very high operating voltages common to the vacuum tube welders to experience pre-arcs in a narrow vee without the presence of scale or slivers to facilitate the short circuit. The very high potential between the edges can result in the same type of arc-over with the same defect.

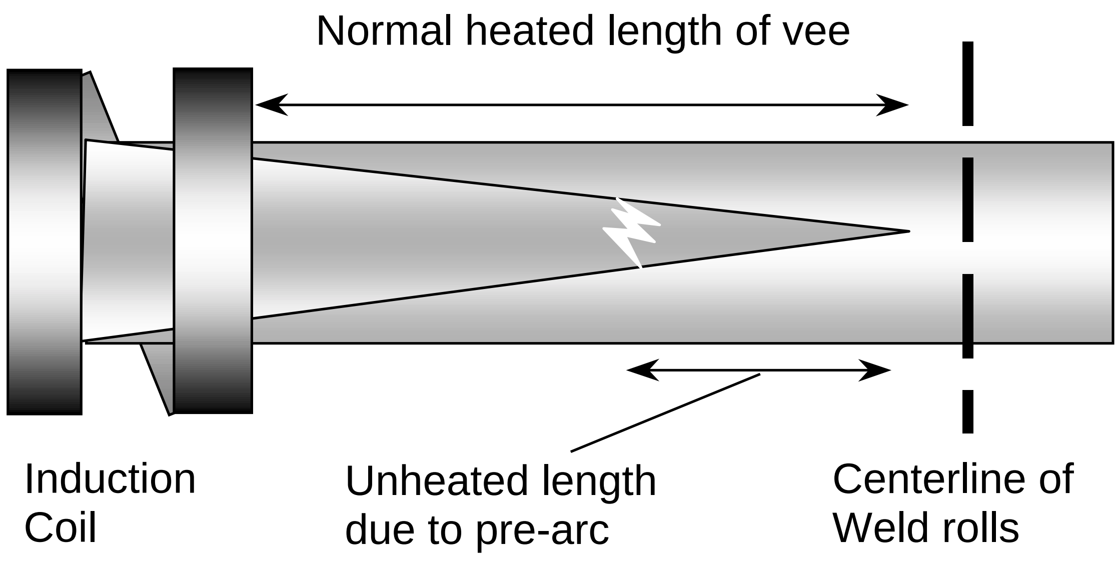


Fig 6

Prevention of Pre-Arcs

1. Maintain a vee angle of 4-6 degrees.
2. Use good slitting practice to minimize slitter burrs.
3. Use good handling practice to minimize damage to the edges.
4. Keep coolant clean and directed away from the vee area.

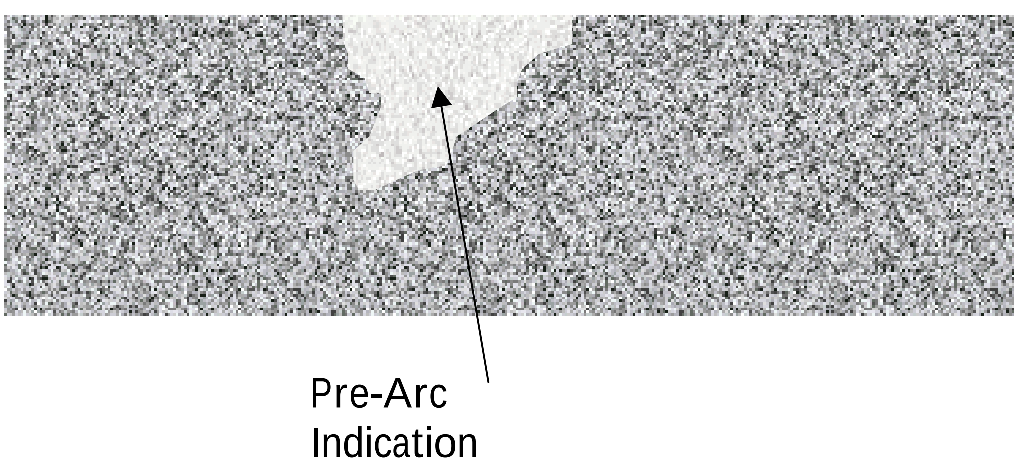


Fig 7

Lack of Fusion (Open Seam)

As the name implies, this is the failure of the two strip edges to fuse to form a sound weld. The edges of an open seam usually show a blue heat tint suggesting that some heat was input (Fig 8). However, the edge face remains flat and smooth, showing no signs of having been molten. The obvious cause of the defect is insufficient weld heat and several factors need be considered. Power setting, vee angle and length, impeder placement and condition, and coil size influence Weld power. All of these factors can work independently or as a group to create a problem. Occasionally, the appropriate heat is input and the seam remains open. This is likely to be related to insufficient squeeze out. Here the edges show evidence of being molten but have not fused because of the oxidized metal remaining on the surface of the molten edges prevents bonding. As the weld passes beyond the squeeze rolls, the strips natural spring back opens the seam.

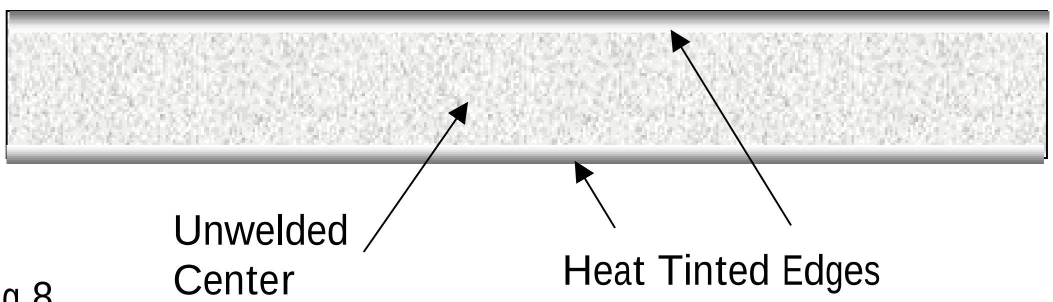


Fig 8

Prevention of Lack of Fusion

1. The actual power setting must be consistent with the speed and material gage;
2. The impeder must be placed 1/8th inch past the weld roll center line and kept cool;
3. The vee length should not exceed approximately 1 tube diameter;
4. The vee angle should not exceed 7 degrees;
5. The coil inside diameter should not exceed the tube diameter by more than ¼ inch.
6. The strip width must be appropriate and consistent for the diameter tube being produced.

Lack of Fusion at Edges (Puckers)

Lack of fusion at the edges of the weld is usually caused by non-metallics on the bond plane. This may be similar to a penetrator that is confined to the outer or inner edges. The defect gets its name from its appearance when the tube is crushed with the weld at the 3:00 o'clock position (FIG 9). When broken open, the pucker area is dark and flat. It can also be the manifestation of peaked edge forming where the OD edges are not heated as hot as the ID edges, in which case the pucker fracture can be silvery in color. Puckers are variations of the entrapment and lack of fusion defects.

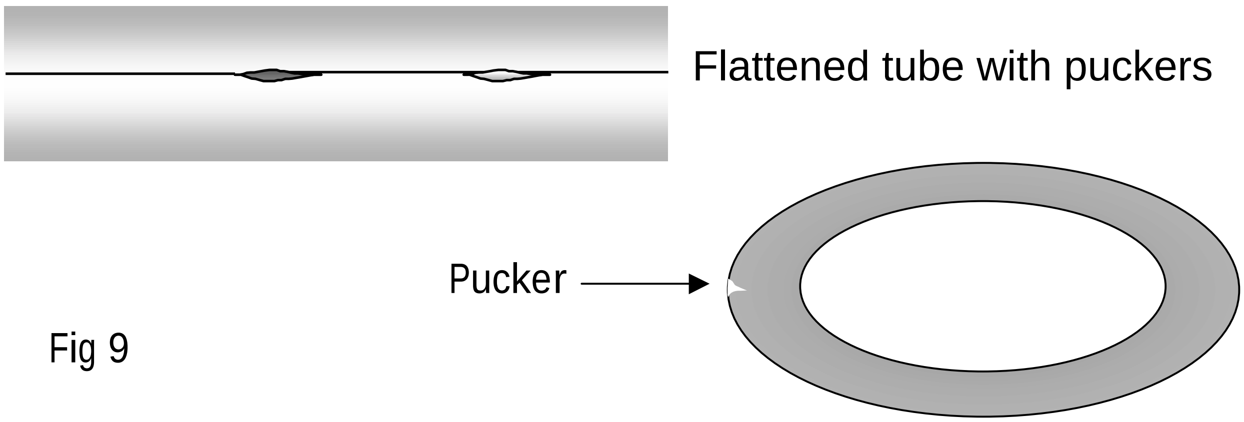


Fig 9

Prevention of Puckers

1. Maintain flat, parallel edges.
2. Use slightly more squeeze out.
3. If pucker is silver, also use more weld heat.

Lack of Fusion at Mid-Wall

When a lack of fusion weld is broken open, the fracture at mid-wall appears to be a flat, dull, silvery band as shown in FIG 10. The edges appear woody and fibrous. This condition is usually caused by running at speeds just beyond the rated power of the welder. There simply wasn't enough time to heat the entire cross-section of the edge to the full temperature and depth required for a sound forge weld.

Lack of mid-wall fusion can also be the result of insufficient squeeze-out although the bond plane for this situation would exhibit some un-extruded molten metal.

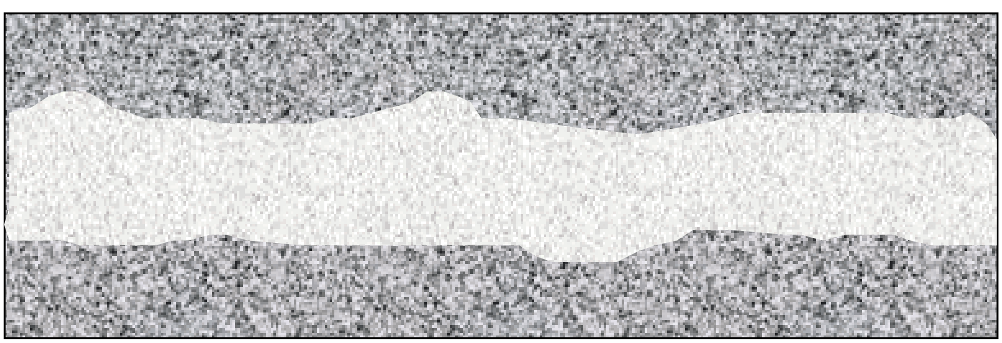


Fig 10

Prevention of Lack of Mid-Wall Fusion

1. Increase weld power.
2. Increase weld upset.
3. Increase vee length or reduce line speed.

Paste Weld (Cold Weld)

Paste welds are perhaps the most dangerous of all HF weld defects because they are virtually invisible to current Non-Destructive Test (NDT) methods. The paste weld is sufficiently bonded to transmit an ultrasound signal but not strong enough to pass normal crush or flare tests. Electro-Magnetic Inspection (EMI) cannot see it because there is no opening in the bond plane. When broken open, the paste weld is very flat and brittle, showing very little of the woody, fibrous structure common to a full fusion weld. Some evidence of the slit edge may still be visible. If looked at in a transverse metallographic section, it would exhibit a very narrow HAZ, no white bond plane and very little upset of the flow lines as shown in FIG 11.

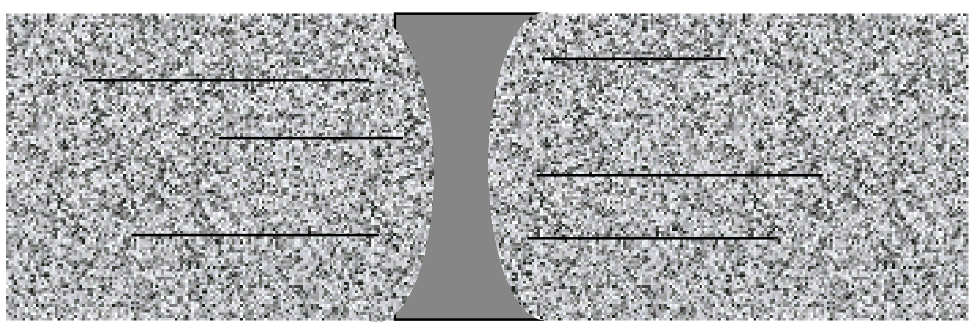


Fig 11

Prevention of Paste Welds

1 Use sufficient weld power for the gage and speed of the mill.
2.Use sufficient squeeze and/or increase strip width.

Cast Weld

A cast weld is the result of failure to eject all of the molten metal from the bond plane. The remaining cast metal on the bond plane likely contains metal oxides similar to the penetrator. The appearance of the fracture surface will vary with the amount of cast metal remaining but will almost always be flat and brittle looking. If examined by metallographic section, the cast metal would be visible on the bond plane as in FIG 12.

The cast weld usually fails the crush or flare tests. Since there is obviously ample power to melt the edges, this defect has a fairly simple solution.

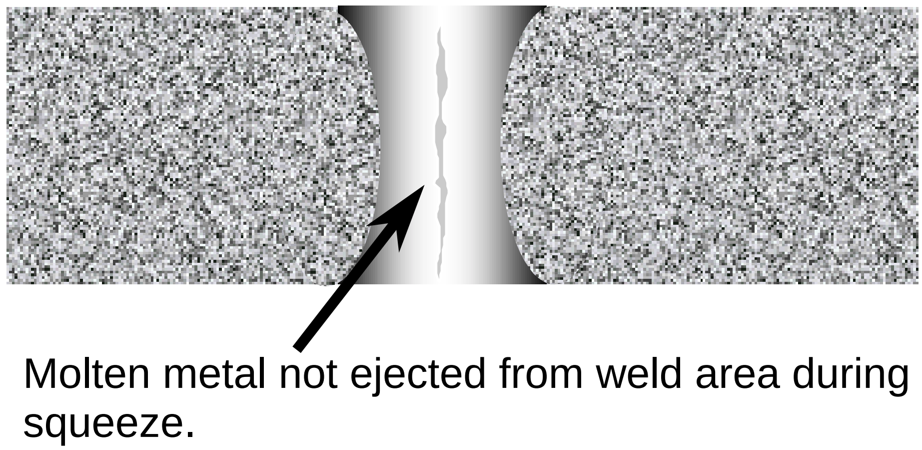


Fig 12

Prevention of a Cast Weld

1. Increase squeeze out.
2. Increase strip width.

Porosity (Pinholes)

Porosity on the bond plane is the result of high welding temperatures and insufficient squeeze out. The fracture surface would appear to be woody and fibrous with shiny, spherical voids randomly distributed across the edge. Where the voids intersect the OD, the surface of the void may be black due to oxidation (FIG 13). Small pinholes may be visible on the OD bead before scarfing. After scarfing, the pinholes may be visible on the bond line.

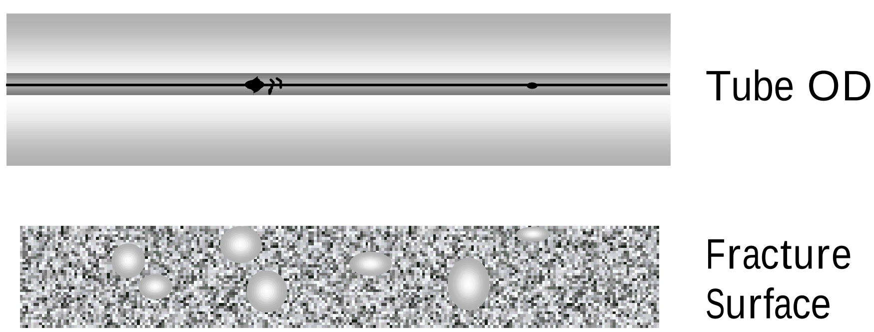


Fig 13

Prevention of Porosity

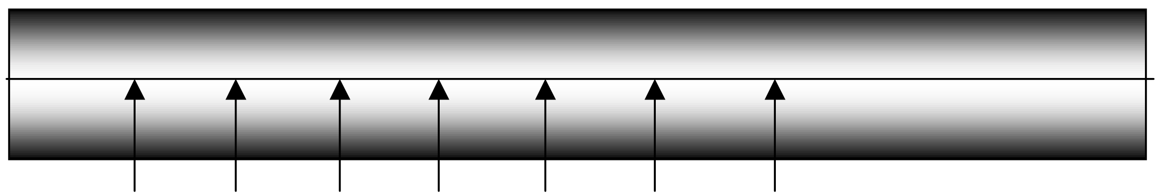
1. Reduce weld heat.
2. Increase squeeze out.

Stitching

Stitching defects can be manifested in a variety of ways but common to all is the fact that the defects are regularly spaced and almost continuous (FIG 14). Usually, the defect takes the shape of puckers on the OD and are spaced some multiple of the power line frequency (60 cycles). If, for example, a line is running at 120 feet per minute and the defects are 4” apart we get:

120 fpm x 12”/foot = 1440 inches / minute,
1440 ipm / 4” = 360 which is a multiple of 60.

It is sometimes possible to get what appears to be stitching with no relationship to a line frequency multiple. In this case, the spacing may be equal to the diameter of a bad roll or a bent shaft, whose periodic movement causes a small defect.



Stitching is a regular pattern of evenly spaced defects

Fig 14

Prevention of Stitching
1.Add additional filtering to weld circuit.
2.Check voltages across incoming phases.
3. Check rolls and shafts.

Trouble Shooting Suggestions

It is likely that several variables may be conspiring to create the defect you are experiencing. A slightly narrow vee would not cause penetrators unless the squeeze out was also just slightly less than necessary. The smaller squeeze out may be the result of slightly narrow slit width or worn tooling or even a bad setup.

Also, the cause of the problem may have its origin outside of the immediate weld area. For example, a cold weld may be the result of an impeder pump cavitating. As the pump fails to deliver adequate cooling water, the impeder momentarily gets hot. When the impeder gets hot, it becomes less effective in focusing the current in the vee. As the current is allowed to spread around the backside of the tube, heat in the vee drops and a cold weld occurs. Turning up the weld heat may prevent the cold weld until the pump fails altogether and the impeder looses all power to focus the current.

Common sense is the best tool to use in locating the root cause of the problem. Try to collect all relevant information about the operating parameters involved in creating the defect. It is very helpful to maintain a setup sheet specifying things like slit width, line speed, plate current and voltage, grid current, reduction in the weld box, etc. A setup report stating the actual settings used can document any changes and help identify defect causes. The root cause may be only slightly out of what is normal for your operation. However, when several other variables are also slightly out of tolerance, the cumulative effect may be enough to cause a defect.

Some manufactures have gone so far as to create a catalog of common defects and their causes. This is of great benefit when new or inexperienced operators are trying to solve their own problems. It also saves a lot of valuable production time and keeps scrap costs to a minimum.

Conclusions

1. Most weld defects have their origins in set-up of the mill or weld area.

2. Standard setup sheets, daily review of setup records and continuous operator training on HF welding can help to minimize errors.

3. Good slitting, handling and coil storage procedures will prevent defects related to edge damage.

4. A good preventative maintenance program will preclude defects due to worn or damaged tooling.