Welding chrome-moly steel

Are tubular wires an option?

By Joe Bundy

September 8, 2010

Welding chrome-moly tube and pipe conventionally is done with shielded metal arc welding (SMAW) or submerged arc welding (SAW). Flux-cored arc welding (FCAW) has been tried, but the wires had some drawbacks that prevented widespread acceptance. Recent developments have reduced some of these disadvantages, so GMAW deserves a fresh look. The switch might lead to improvements in the weld's characteristics or welding productivity.

Companies traditionally have relied on shielded metal arc welding (SMAW, or stick) electrodes for welding chrome-moly tube and pipe, in part for the mechanical and chemical properties they provide and in part because they are the accepted standard specified for such applications. However, with greater demands to increase productivity and stay competitive, some companies are considering a wire welding process as a means to get ahead. Some have begun to use T-1 or T-5 gas-shielded, flux-cored wires, both of which have undergone significant advancements in recent years and offer greater consistency than similar products offered in the past.

Like any filler metal, flux-cored wires for chrome-moly have distinct advantages and disadvantages. Flux-cored wire’s main advantage is speed. Because it comes on a spool and is hundreds of feet long, it can provide a long, continuous weld, which is much faster than stopping to get a new stick after 12 or 15 inches of welding. However, flux-cored wire isn’t the best consumable for every welding job. Learning about the main types of flux-cored wire for chrome-moly tube and pipe is the first step in considering the switch.

What You Should Know About T-1 Wires

Flux-cored wires referred to as T-1 have a rutile (or acidic) slag system. Suppliers often offer T-1 wires in several product classes to match the chemical and mechanical properties of various chrome-moly tube and pipe. These wire classes include B2, B3, B6, B8, and B9, which contain from 1.25 to 10.5 percent chrome and 0.5 to 1 percent molybdenum (see Figure 1).
A T-1 wire’s slag system results in an easy-to-remove slag and makes the wire well-suited for welding on multipass applications because it requires minimal cleanup between passes. This category of wire also creates low amounts of spatter, which reduces the need for postweld cleaning.

Typically, T-1 flux-cored wires for chrome-moly have a table arc and weld smoothly. Consequently, they appeal to welders across a broad skill range, even those with little flux-cored arc welding (FCAW) experience. The wires operate with either 100 percent CO₂ shielding gas or a blend of argon and CO₂ (usually in a 75/25 percent mixture) and provide a high deposition rate. They also create well-shaped, uniform, and smooth weld beads and are available in low-hydrogen versions. In the past T-1 flux-cored wires were available only in H16 or H8 versions, meaning they had 16 or 8 milliliters of diffusible hydrogen, respectively, per 100 grams of weld metal. Some of today’s T-1 flux-cored wires are available in an H4 version; as the designation implies, they have as little as 4 ml of diffusible hydrogen per 100 g of weld metal.

Additionally, many T-1 flux-cored wires also are useful for out-of-position welding, allowing their use on existing piping systems. Steam piping, heat exchangers, and other high-temperature, corrosion-resistant applications are common examples that can benefit from these wires. The ability to weld out-of-position provides a distinct advantage over other processes, such as submerged arc welding, which are suitable for use only in the flat position or while the tube or pipe rotates.

That said, T-1 wires do have disadvantages that limit the chrome-moly applications on which they can be used. First, T-1 flux-cored wires tend to create welds with slightly higher oxygen content than other filler metals, typically 600 to 1,200 parts per million (PPM). Compared to stick electrodes or T-5 flux-cored wires (to be discussed later), this higher oxygen content reduces the toughness of the T-1 weld in both the as-welded and post-weld heat-treated (PWHT) conditions. Cool ambient temperatures aggravate this characteristic, so T-1 wire is not the best candidate for applications such as the cold start of a power plant that has been shut down or a piping application subject to extremely cold weather. As a rule, T-1 flux-cored wires for chrome-moly also have higher weld metal hardness compared to a stick electrode or submerged arc wire, which makes them more prone to cracking.

### T-5 Wires: A Viable Alternative?

T-5 flux-cored wires are a potential alternative to T-1 wires, especially for applications requiring good toughness, as they feature a lime-fluoride (also referred to as basic) slag system capable of providing clean welds with low sulfur and oxygen content. Specifically, T-5 flux-cored wires have a high capacity for absorbing oxygen, resulting in an oxygen level of about 400 to 700 PPM, which is substantially less than the 600 to 1,200 PPM in a T-1 weld deposit. This lower oxygen level improves the toughness regardless of the application’s temperature.

Newer versions of T-5 flux-cored wires, including those with an American Welding Society classification of E81T5-B2M H4 (among others), have even lower levels of oxygen in the final weldment. Some are less than 200 PPM.

In general, T-5 flux-cored wires also have low diffusible hydrogen levels, 4 to 8 ml per 100 g of weld metal, and therefore have good crack resistance. They also are porosity-resistant, making them suitable for casting weld repairs that may contain moisture.

Like T-1 wires, T-5 wires have drawbacks. T-5’s basic slag system has a low melting point that creates a weld puddle that is usually too fluid for out-of-position welding, making these wires unsuitable for repairs on an existing, immovable piping system. Also, controlling the puddle is challenging, so T-5 isn’t the best choice for less experienced welders. They also tend to have a less stable arc and generate more spatter than T-1 wires. In
many cases, they are not as efficient for multipass welding due to their difficult-to-remove slag, which requires more chipping between weld passes than a T-1 wire.

Typically, suppliers offer T-5 flux-cored wires for chrome-moly applications in two product classes: B2 and B3. The wires in the B2 product class contain 1.25 percent chrome and 0.5 percent molybdenum and are well-suited for welding P11 chrome-moly pipe that is subject to high-temperature service conditions. The B3 product class contains 2.25 percent chrome and 1 percent molybdenum. They are typically used for welding P21 and P22 chrome-moly pipe and are also good for high-temperature applications.

Ultimately, the challenge of T-5 wires is that they can be difficult to use and usually are limited to flat and horizontal welding positions. In recent years, however, new versions of T-5 flux-cored wires have emerged, including the E81T5-B2M H4 wire mentioned previously, along with those classified as E91T5-B3M H4. These wires have slightly different characteristics than traditional T-5 wires—namely, they are more readily weldable out of position, particularly vertical-up and vertical-down.

These wires operate with a mixed shielding gas (argon and CO₂) rather than straight CO₂, which provides a stable arc similar to, but not as steady as, that of a T-1 flux-cored wire. As a result, these wires often are easier to train welding operators to use, but they still provide the toughness desired with a traditional T-5 wire. Usually they have impact properties of more than 37 joules at -58 degrees F in the as-welded condition. In the PWHT condition, they can offer toughness greater than 47 joules at -40 degrees F. These newer T-5 wires typically have greater slag coverage as well. The slag provides good-quality welds, yet is relatively easy to remove.

One disadvantage of these newer wires, however, is that unlike other T-5 wires, they operate on DC, negative polarity (DCEN) and therefore require a different power source. Also, the weld puddle on these wires types tends to behave differently than other T-1 or T-5 wires, which may require additional welder training to use them properly.

**The X-Factor**

With these newer wires, as well as the traditional T-5 flux-cored wires and T-1 wires, the X-factor is critical. The X-factor is a formula that measures a weldment’s resistance to temper embrittlement, which is the brittleness, or loss of toughness, that occurs when the weldment is held (or slowly cooled) through a temperature range of approximately 850 to 1,100 degrees F. It is particularly important when welding chrome-moly. For all types of flux-cored wire welding of chrome-moly, the X-factor should be below 15.

**Making the Choice**

Determining whether an application can benefit from a T-1 or T-5 welding wire depends on several factors, including whether the specifications for the particular chrome-moly application can be changed. In some circumstances, it may simply not be an option to change from stick or submerged arc welding. In others, switching might not improve the weld. However, the latest T-1 or T-5 flux-cored wires are worth a look because, in some cases, they may improve productivity and help companies gain a competitive edge.
Field welding repair

Key steps and equipment selection

By John Leisner

June 9, 2009

Welding to repair damaged components in broken equipment involves three stages, each of which must be performed meticulously to ensure that the machinery runs properly and the repair lasts a reasonable length of time. What are these stages, and what equipment do you need to complete them?

Welding to repair damaged components in broken equipment involves three stages, each of which must be performed meticulously to ensure that the machinery runs properly and the repair lasts a reasonable length of time. What are these stages, and what equipment do you need to complete them?

Engine-driven welding generators feature 5,500 to 20,000 watts of generator power, depending on the model, for running grinders (pictured), drills, and other tools needed for field repair. Broken equipment—whether it's a large excavator in a gravel pit or a conveyor belt in a processing plant—eats away at your profits. You can almost hear the money blowing away in the deafening silence of an idle machine.

Repairing broken steel components in the field requires mastery in three areas:

- Cutting and removing the failed component
- Preparing the new joint/part
- Welding and cleanup

Cutting and Removing the Failed Metal

The first step in welding repair is to remove the damaged metal. This can be done with oxyfuel or plasma cutting or carbon arc gouging. Oxyfuel and plasma typically are better for cutting through metal, whereas carbon arc gouging is better for gouging out a crack or defect without completely severing the part.

Oxyfuel torches, one of the most common tools for cutting, usually can be found on most service trucks. Plasma cutters, however, produce a smaller kerf (cut width), a smaller heat-affected zone (HAZ), and typically are faster than oxyfuel torches. Plasma cutters also cut through all electrically conductive metals, whereas oxyfuel can't cut through aluminum or stainless steel.
Carbon arc gouging is another cutting/gouging option when using welding generators with 300 to 500 amps of output and a high duty cycle. Carbon arc gouging uses a carbon electrode to melt the defective area and blast away molten metal with a focused, high-pressure stream of air.

To begin the repair, cut away the damaged area and remove all rough edges to ensure proper fit-up of the replacement part. It is extremely important to fully grind out all cracks—even beyond what's visible—because even the slightest remnant of a defect will continue cracking, even after a weld is laid over it.

**Preparing the Weld Joint**

Choosing the correct replacement/filler material is critical. All components should be replaced with a material that meets or exceeds the strength of the parent material. Each application varies in mechanical properties, such as, ductility, wear resistance, impact strength, and tensile strength. An exact material match ensures weld quality and longevity and helps to prevent premature failure and unwanted downtime.

The downtime for repair also provides an excellent opportunity to reinforce trouble spots. A part that breaks in the same place more than once might need to be reinforced with additional steel.

Once you've obtained the right alloy, cut the steel to its required size and bevel the edges at a 30-degree angle for better welding penetration. For heavier sections of material, it is recommended to leave a small land at the bottom of the joint. This can be done, after beveling your edges, by grinding along the surface until the bottom portion is about the thickness of a nickel.

Welding joint cleanliness is critical. While some welding processes are more forgiving than others, it's never wise to leave any contaminants behind. All rust, oils, and paints must be ground or wiped away before welding; failure to do so will lead to a failed or weakened weld.

Once the piece is in place, it may be necessary to preheat the weld area. Preheating is done to remove hydrogen and other gases, reduce the maximum hardness, minimize shrinkage stresses, and minimize distortion, all of which might cause cracking when an extremely hot welding arc is applied to cold steel. Preheating typically is required on all material thicknesses when the carbon content of mild steel exceeds 0.40 percent. Consult your material supplier for specific material and process requirements.

To preheat, use an oxyfuel torch outfitted with a special "rosebud" tip that widens the flame. Preheating temperatures vary based on the material to be welded. A temp stick (or heat crayon) can be used to gauge the temperature as it changes. Temp sticks come in various temperature values and, when applied to the material being heated, change color when the target temperature is reached. Again, consult your material supplier for specific material and process requirements.

**Which Welding Process Should You Use?**

The two most common processes for field welding repair are shielded metal arc welding (SMAW), or stick, and flux cored arc welding (FCAW), or flux cored. Stick electrodes are self-shielded, as are many flux-cored wires designed for this application. Self-shielded processes reduce the amount of equipment needed—no need to haul in a gas cylinder, hose, and regulator. Adequate protection of the weld bead in outdoor applications in which wind interferes with shielding gases is more achievable using either the stick or flux-cored process.

Common electrodes used in stick welding are 6010, 6011, 6013, 7018, and 7024 with common diameters ranging from 1/8 to 5/32 in. Each of these electrodes offers all-position welding capabilities (except 7024). The first two digits of a stick electrode represent the "as welded" minimum tensile strength: 6010 provides 60,000-PSI tensile strength, for instance.
A common wire for flux-cored welding in repair applications is the self-shielded, general-purpose E71T-11 wire. Another option is E71T-8JD H8. These wires are all-position, multipass wires with good impact properties at low temperatures. FCAW can replace and improve productivity over 7018 stick welding in certain applications. Both wires offer higher deposition rates than stick electrodes, and the slag removes easily. An added benefit of flux-cored over stick is that with the former, there typically is no need to switch between wire types or sizes for the same repair. This allows you to lay bead after bead while stopping only to remove slag.

**Welding Equipment Selection**

![Welding Equipment Selection](image)

**Figure 1**
All-in-one machines that can plug into both 115- and 230-volt power provide field welding repair flexibility without having to constantly link back to a welding generator on a service truck.

Selecting the right machine for stick welding is based largely on the diameter of electrodes to be used. A 1/8-in. electrode welds up to 145 amps, while a 5/32-in. rod performs optimally at about 180 amps. Therefore, a welding generator with a 100 percent duty cycle at 250 amps offers enough welding power to meet most stick welding needs.

For flux-cored welding, a welding generator with constant voltage (CV) output provides superior wire weld performance versus a constant current (CC) machine. A CV output also is necessary for short-circuit gas metal arc welding (GMAW) for general fabrication. Amperage requirements vary based on the type and diameter of wire you are using, but 250 to 350 amps is sufficient for most applications.

You also need to match your welding generator with a wire feeder for flux-cored welding. There are two options for field work: portable suitcase wire feeders with either remote voltage controls or voltage-sensing capabilities. A remote control machine offers voltage and wire feed speed control at the feeder and no mechanical contactor, which lowers its weight. These machines require a welding generator with a 14-pin receptacle and an extra cord between the feeder and the welder. This limits this particular feeder to within 100 ft. of you. A voltage-sensing wire feeder, however, works with any welding generator and is easy to hook up with no additional cables. The only real downsides to a voltage-sensing feeder are the lack of voltage control at the feeder and a little extra weight from its mechanical contactor.

On the opposite end of the size spectrum are portable, all-in-one machines (**Figure 1**) for repair in hard-to-reach locations (deep inside a plant, high up on scaffolding). These machines offer GMAW and flux-cored capabilities up to 150 amps and can plug into any 115- or 230-V power. This provides a portable, remote field welding solution for jobs for which it may be tough to get a truck near the weld. You can even perform repairs
on stainless steel and aluminum by using the self-contained gas cylinder and by adding a spool gun with the all-in-one machines.

**Factors to Consider for Gouging, Power Generation, and Air Supply**

![Image of a welder](image)

**Figure 2**
Machines that comprise welders, generators, and air compressors in the same unit take only half the bed space of a separate engine-driven air compressor and welder, freeing up 50 percent more room on your truck for equipment and supplies.

To perform carbon arc gouging, you need to make sure your machine is rated for the carbon diameter you want to run.

Contractors have come to expect the dual welding and power generation capabilities of engine-driven welding generators (**Figure 2**). These machines save space on maintenance trucks by eliminating the need for a stand-alone generator and have the power to run grinders, drills, chop saws, lights, and air compressors. Some machines have two separate generators in the same unit—one for the welding arc and one for auxiliary tools. Keeping these generators separate allows a worker to fire up any tool off of the machine's generator while another person is welding without affecting the performance of the welding arc.

For heavy-duty repairs and space savings on maintenance trucks, fleet managers might consider options that also include self-contained rotary screw air compressors for running air tools and plasma cutters.

Another factor to consider when selecting an engine drive is fuel. Most welding generators are available in gasoline and diesel. Gas engines offer a lower product cost, reduced weight, and smaller size. Diesel engines use 20 to 35 percent less fuel, have longer engine lives, and are required on certain sites. Choose whichever fuel option best suits your needs and work environment.
Brazing copper and copper alloys

When to use it and how to do it

By Myron T. Havis

March 13, 2007

It is important to be able to identify when brazing is suitable for joining copper or copper alloys, how it is applied, and which filler metals to use.

![Figure 1](image)

**Figure 1**
Brazing takes place above 840 degrees F but below the melting point of the base metal. Source: CDA, Copper Tube Handbook.

Four processes to consider when joining copper and copper alloys are mechanical couplings, welding, soldering, and brazing. Brazing is suitable for small parts and when high joint strength is required. According to the American Welding Society (AWS), the strength of a brazed joint can meet or exceed that of the metals being joined. It is important to know when to choose brazing and how to perform the process.

From a process standpoint, soldering and brazing are essentially the same. The only differences are the filler metals used and the amount of time and heat required to complete the joint. AWS defines soldering as a joining process that takes place below 840 degrees F, while brazing takes place above 840 degrees F but below the melting point of the base metal. In actual practice for copper systems, most soldering is done at temperatures from about 450 degrees F to 600 degrees F, while most brazing is done at temperatures from 1,100 degrees F to 1,500 degrees F. When brazing copper tube, however, the annealing of the tube and fitting that results from the higher heat can cause the rated pressure of the system to be less than that of a soldered joint.

Copper's melting point is 1,981 degrees F (liquidus) and 1,949 degrees F (solidus). For brazing, it is important to know the melting points of the metals to be joined and the filler metal. The difference between the solidus and liquidus state is the melting range, which may be important when selecting a filler metal. It indicates the width of the working range for the filler metal and the speed with which the filler metal solidifies after brazing.
Filler metals with narrow ranges, with or without silver, solidify more quickly and, therefore, require careful application of heat. The liquidus temperature is the minimum at which brazing will take place. See Figure 1 for the melting ranges of some common brazing metals.

**To Braze or Not to Braze**

![Figure 1](image.png)

**Figure 1**
The table shows how fluxes respond at various temperatures and at what maximum temperature the flux will protect the metal. Source: CDA, Copper Tube Handbook.

According to Luca Milhaupt's What Brazing Is All About (www.lucasmilhaupt.com), the choice to braze comes down to five factors:

1. The size of the parts to be joined. Brazing is more often used for small parts and requires heating a broad surface to bring the filler material to its flow point, which is often impractical with large pieces.
2. Thickness of the metal sections. The broader heat and lower temperature used in brazing, as opposed to welding, permit the joining of sections without warpage or metal distortion. The intense heat of welding may burn through or warp a thin section.
3. Joint configuration. Brazing needs no manual tracing, and the filler metal is drawn through the joint area by capillary action, which works with equal ease on straight, irregular, or tubular joints.
4. Nature of the base metals. For joining dissimilar metals, brazing won't melt one or both of the metals if the filler metal is metallurgically compatible with both base metals and has a melting point lower than either of the metals to be joined. Note that copper alloys can be readily brazed to other metals, such as cast iron, tool and stainless steels, nickel alloys, and titanium alloys.
5. Number of joints to be made. If you are making many joints, manual brazing is quick and simple, and automated brazing may be accomplished inexpensively using simple production techniques.

**Brazing Fluxes**

Brazing fluxes for copper are water-based, dissolve and remove residual oxides from the metal surface, protect the metal from oxidation during heating, and promote wetting of the surfaces to be joined. Brazing fluxes also provide you with an indication of temperature (see Figure 2).
Figure 3
This table, a reference for brazing all copper and copper alloys, includes information for selecting the proper filler materials and fluxes, surface preparation, and atmospheres for brazing. Source: AWS, Welding Handbook.

The most commonly used fluxes and brazing filler materials for copper and copper alloys are shown in Figure 3, and a guide to their use is shown in Figure 4. This and other detailed information can be found in The Welding Handbook, 8th Edition, Vol. 8, published by the American Welding Society and available from the Copper Development Association under the title Welding Copper and Copper Alloys, A1050-72/97.

Figure 4a
This copper brazing guide lists commonly used filler metals, fluxes, atmospheres, and special considerations. Source: AWS, Welding Handbook.

The Process
The same basic steps are used for brazing as for soldering, with the only differences being the use of fluxes, filler metals, and the amount of heat used.
In general, both lap and butt joints can be made. Be sure to remove all oxides and surface oils with abrasive cloth, pads, or brushes before joining the metals. Such contaminants interfere with the proper flow of filler metal and may lessen the joint strength or cause failure. Chemicals cleaners may be used if they are thoroughly rinsed off, but be sure you don't touch the clean surface with bare hands or oily gloves.

Apply a thin, even coating of flux with a brush to both surfaces soon after cleaning. Do not apply the flux with your fingers because the chemicals in the flux can be harmful if it comes in contact with your eyes, mouth, or open cuts. Copper-phosphorus and copper-silver-phosphorus metals (BCuP) are considered self-fluxing on copper-base metals.

Support the surfaces securely and ensure an adequate capillary space between them for the flow of the molten brazing filler. Excessive joint clearance can lead to cracking under stress or vibration. A joint clearance of 0.001 to 0.005 in. will develop the maximum joint strength and soundness.

Use only the amount of heat necessary to melt and flow the filler metal. Overheating the joint or directing the flame into the capillary space can burn the flux, destroying its effectiveness and preventing the filler metal from entering the joint properly. Apply the heat around the joint area to draw the filler metal into the capillary space. When dealing with an open flame, high temperatures, and flammable gases, safety precautions as described in ANSI/AWS Z49.1, "Safety in Welding, Cutting and Allied Processes," must be observed.

Allow the completed joint to cool naturally. Shock cooling with water may stress or crack it. When it is cool, clean off any remaining flux residue with a wet rag and test all completed assemblies for joint integrity.
Weld repair—Analyze the failure before attempting the repair

By Elia Levi

November 9, 2004

When something breaks, you acknowledge the shock, scratch your head, take stock of the situation, and look for the fastest way to repair the item and put it back into operation. The pressure to repair quickly is understandable, but common sense suggests stopping for a moment and trying to understand what caused the break before attempting the repair.

Failure Analysis

Almost anything can fracture. The science investigating the origins of fractures is called failure analysis, and it is used to establish responsibilities for fractures and to determine preventive measures for avoiding future occurrences. An introductory, interesting book on this subject was written by Donald J. Wulpi and is titled Understanding How Components Fail.

Service Failures

This article discusses only in-service weldment breakage, also described as service failures. Weldments are assemblies with parts joined by welding. Failures occurring during or immediately following welding are easier to deal with, because all conditions are known.

So if the item was welded originally, it should be weldable again for repair, right?

Yes, but only if you know the materials and their conditions and whether they still are exactly as they were at fabrication time—no heat treatment or other surface conditioning has been introduced. You also must know the precise process and welding procedure that were used in the first place, which usually isn't the case.

What Caused the Break?

Before attempting any repair, you must determine why the break occurred. If you restore the item exactly to its original condition, chances are another breakage will occur. (At that time it may well be none of your concern, but you must operate professionally at all times).

While a fully implemented professional investigation by an experienced metallurgist would be the best recourse, this usually is justifiable only in selected cases—for example, for presenting claims to the manufacturer or to the insurance company. It is mandatory, however, if injury to persons or property loss was or could have been involved.

Left to involved people, the human urge to clear oneself and to find fault in someone else's actions or inactions can interfere with an investigation.
The main reasons that weldments fail are:

- Inadequate material or properties.
- Poor design.
- Poor workmanship.
- Excessive unanticipated service conditions.

**The Investigation Process**

Even if the person in charge is not specifically trained as a failure analyst, a few investigative steps should always be taken:

1. First take care that nothing be moved, manipulated, reassembled, or fixed.
2. Document the condition of the weldment when the breakage was found.
3. Write down all that is known, and question all who were present.
4. Note the ambient temperature at the time of occurrence.
5. Take pictures, both general and close-ups.
6. Protect the place from rain and other environmental disturbing factors.

Firmly resist the pressing urge (your own and of those around you) to supply a theory for the breakage, especially before having assembled all the information.

A description of the weld profile as visible under low-power magnification should include such details as dimensions and fit-up as much as they can be determined visually. If possible, these details should be compared with design requirements.

When the structure operates normally at elevated temperature, it is probably under some code legislation that may request an official investigation.

A weld breakage usually is a crack or a fracture. Much information can be drawn from an exact description of the failure. A crack should be characterized by its dimensions, by its orientation (longitudinal, along the weld bead, or transversal), and by its position relative to the weld itself (on the weld bead or on its sides, in the heat-affected zone, or in the base metal).

If the fracture is open, do not reassemble the mating parts. Doing so can obliterate important clues. Inspect the fractured surfaces with a low-power lens or microscope that can show internal defects like gas holes or pores, nonmetallic inclusions, or indications of fatigue failure in the form of concentric *beach marks*.

The presence of macroscopic deformations and the fibrous or glassy aspect of the surfaces should be assessed to reveal if the failure was ductile (with deformation) or brittle (without deformation).

Specific colors on the surfaces should be remarked; they might be clues about local heating and oxidation. The extent of corrosion, if present, has to be determined and documented.

The presence of arc strikes on the surface, improper starting conditions, or accidental contact may be at the origin of considerable damage.

Hardness testing is a very informative, simple, nondestructive test. However, selecting the proper locations, especially if the weldment must be sectioned for testing, may be beyond what can be expected from a technician not specifically trained for this kind of investigation.
The materials involved should be known and their properties checked for conformance to specifications. No weld repair should be attempted without this essential knowledge. Having this information allows you to select the proper repair procedures and filler metal.

If materials are not known, an effort should be made to provide at least qualitative information. This information can be obtained by X-ray fluorescence, a nondestructive test readily available from many metal-related services.

**What Next?**

Having assembled and organized all the facts, you now should be able to formulate an educated guess as to the possible causes of the failure.

Was faulty workmanship the culprit? A professional investigation service uses metallographic examinations of weld sections to look for weld defects in the original weldment. Obviously, faulty welds should have been detected by inspection after manufacturing, but nobody is perfect. If the original weld was faulty, a repair weld performed with utmost care should improve the future in-service performance of the repaired item.

A design change is not normally applicable for repair. However, if it is clear a faulty design caused the failure, an improvement might be introduced. But you should be aware that adding stiffness may make the matter worse, by increasing internal stresses and paving the way for the next fatigue fracture.

If the breakdown was sudden but caused by a progressively deteriorating condition of certain components (as in the case of fatigue fractures or corrosion), a corrective action program should be initiated. The plan has to incorporate periodic examination of the parts involved, after the structure is repaired, to detect dangerously spreading cracks before much damage occurs again.

Cracks must be removed completely by careful grinding before rewelding. If the base metal is in acceptable condition, weld repair may be attempted with suitable ductile filler metal or low-hydrogen electrodes.

The process selected should introduce minimum heat and residual stresses, and possibly should be followed by light hammer peening. Preheat and/or postheat, if necessary.

If separation has occurred, then a proper joint has to be designed and prepared, possibly by introducing a transition element to make up for the volume of metal to be discarded.

Experience and common sense always are important, and even more so when dealing with weld repairs.

*Understanding How Components Fail* by Donald J. Wulpi is available from [http://www.asminternational.org/](http://www.asminternational.org/). Click on Bookstore, then on Failure Analysis, and then on *Understanding How Components Fail*. 
Delta repair welders aim high

An introduction to GTAW repair at Delta Air Lines

By Jody Collier

July 13, 2004

Pilots refer to flying experience as "seat time." For the 300-plus certified welders in Delta Air Lines' TechOps division, the term has a similar meaning. Certification is just the first step for them. Qualified GTAW welders here log plenty of seat time.

Whether they maintain ground support equipment like deicing trucks and luggage carts or critical aircraft components like engine gearboxes or cylinder sleeves, these welders know that lives depend on their expertise.

To train and certify the welders, Delta instituted a Welding Training Department at the airline's maintenance headquarters at Atlanta's Hartsfield International Airport. Although the majority of welders work at the TechOps division, the welding training instructors—program manager Jody Collier and instructor Robert Trudelle—also are responsible for training and certifying welders at the airline's smaller maintenance facilities, two of which are in Dallas and Tampa, Fla. All of Delta's maintenance facilities operate under the TechOps division.

The task is large. Delta's welders hold more than 1,000 different certifications. Each certification is differentiated by material type, process, and whether the part is nonflight hardware or an aircraft component.

The training and certification process for aircraft welders runs six to eight weeks, depending on the candidate's expertise. Each welder must be recertified every two years.

Welding training covers every welding process on every type of metal, from 1-inch thick carbon steel to 0.001-in. INCONEL® alloy or stainless steel. For all nonflight hardware, training focuses on three processes: gas metal arc welding (GMAW), shielded metal arc welding (SMAW), and gas tungsten arc welding (GTAW).

Creating Skilled GTAW Welders

Manual welding for aircraft component maintenance and repair is all GTAW. The materials are thin, and the welds must be precise. Because filler metal doesn't cross the arc, spatter isn't a problem. The welding area is clearly visible, and postweld cleaning is minimal.

The welders' GTAW skill is relatively high, especially for aircraft component welders. Every test weld either is X-rayed or metallographically tested to spot various possible defects such as crater cracking or underfill, so preventing heat distortion is critical. All welders are trained to weld short runs—1¼2 to 2 in. depending on the part—to minimize heat input. Starting and stopping without creating defects is key to welding aircraft components.

Training and certification are conducted on eight different metal categories. The categories are taken from industry standards AWS D17.1 for aircraft welds and AWS D1.1 for structural welds. The categories are:
1. Group 1, carbon and low-alloy steels
2. Group 2, stainless steels
3. Group 3, nickel-based alloys
4. Group 4, aluminum
5. Group 5, magnesium
6. Group 6, titanium
7. Group 7, cobalt alloys
8. Group 8, refractory alloys, such as niobium and columbium

Training progresses through the categories, and practical exercises conclude each step. Each practical exercise must pass a visual inspection and either X-ray or metallographic testing before the welder advances.

After the eight-week training and certification process, welders are assigned to individual departments that require on-site welding or to the TOC's central welding shop, which has a pool of 30 welders. Once in the assignment, a newly certified welder undergoes a period of on-the-job training with a qualified welder before he or she is considered qualified.

Metal preparation is critical to GTAW repair. Weld training emphasizes the three C's: clean, clean, clean. Titanium and niobium, for example, require stringent cleaning procedures using solvents and wire brushing to clean the joints. For other metals, such as stainless steel, wire brushing alone is preferred to using abrasive cleaners.

It's standard practice to spend more time cleaning and preparing a part than welding it. In many instances, the weld process itself may take 30 seconds; the repair of a 1-in. crack in a niobium heat barrier shield that shrouds a jet engine is one example. Critical to that weld, however, is the preparation: cleaning the surface properly, fixturing the part, and ensuring the back side of the weld is shielded. For most aircraft repairs, the shielding gas is 100 percent pure argon. The exceptions are an 80/20 mix of helium and argon for certain aluminum applications in which distortion control is critical; and a 50/50 argon and helium mix for certain magnesium applications.

**Shielding Gas Practices**

To shield the back side of the weld locally without having to wait to purge an entire vessel or cavity, Delta's welders use backup boxes. For example, to repair a 3-in. crack in a 6-in.-dia. INCONEL alloy exhaust duct, one alternative is to enclose the ends, slide an argon tube into the duct, and purge the entire inside.

A faster, more focused method is the backup box. Made of perforated material—typically copper—the backup box is contoured to fit on the back side of the exhaust duct. Once the box is clamped in place and the argon gas turned on, the back side is shielded immediately. The welder doesn't have to wait for a purge or employ an oxygen-monitoring system to ensure the shield is adequate. Backup boxes can facilitate quick and complete repairs, and given that aircraft components susceptible to wear will do so again and again, TOC welders' toolboxes contain 20 or more handcrafted backup boxes.

Delta welders also use a unique type of GTAW nozzle that provides a larger gas shield to any aircraft part. Whereas a standard-size nozzle provides about a 7¾16-in. shielding gas envelope, the larger GTAW cup provides up to a 1-in. envelope. The benefit of this nozzle comes into play on all of the stainless steel and nickel-based alloys.

Typically, aircraft parts made of those alloys contain a small amount of aluminum, and because of it, welders will get some mild oxidation while welding. A larger welding cup enables a cleaner weld that requires less amperage. If less amperage is needed to move the puddle because it's shielded perfectly and therefore is less
sluggish, heat input and distortion are reduced. For example, if a welder is working on 0.0020-in. stainless steel at 13 amps, the larger cup can save 5 amps, which is considerable when heat distortion is a concern.

Most aircraft repairs are in locations that require unconventional welding techniques. The shielding afforded by the larger nozzle allows welders to extend their tungsten out farther to get into those locations. If the weld is inside an exhaust duct or radial drive sleeve, the tungsten can stick out as far as 11¼2 in. and the operator will still have adequate shielding (see introductory photo).

**GTAW Repair Fundamentals**

Given the range of metals used and their thinness, three fundamentals are critical in aircraft component GTAW repair: a clean part, clean shielding, and heat input. To illustrate this point, metals frequently encountered include aluminum, INCONEL alloys, niobium, and magnesium.

To repair the service wear on aluminum radial drive sleeves, the welder applies a buildup weld to cover the wear pattern, which allows the groove to be remachined. The goal is to create an edge no more than 0.0010 in. deep; any more risks distortion and will require more machining of the part. With an AC/DC GTAW inverter set to 70 amps AC, a 160-Hz frequency, and 70 percent electrode-negative balance, the operator uses 4043 aluminum filler wire with a tapered electrode instead of a blunt end. This allows him to pinpoint the heat instead of fanning it beyond the groove.

When repairing a jet engine air cycling machine of 5052TL aluminum, the welder sets his AC GTAW inverter to 75 amps. He uses 4043 aluminum filler wire and a 70/30 argon and helium shielding gas to counteract the thin material.

When repairing an INCONEL alloy exhaust duct, the goal is to control the heat buildup. To repair a deep gouge, the welder lays a bead of INCONEL 625 wire in the gouge to flatten it and then runs stringer beads along the cavity to build it back up. Running DC electrode negative at 40 amps, the welder's main concern is to control the heat to prevent warpage, which will distort the duct and make reassembly into the exhaust system impossible.

To rebuild a lug mount on the front cover of a magnesium engine gearbox, the welder spends three and a half hours building the mount with 1¼8-in. AZ101 magnesium filler metal. Approximately 2 in. deep by 11¼2 in. high, the mount is created by welding pass after pass and allowing the weld to cool down after every three passes. When the welder restarts, he changes direction to avoid creating any stress lines in the weld. Shielding gas is a 50/50 argon and helium mixture for more heat input and a hotter arc. This allows the welder to increase his travel speed because the metal puddles faster and he can get in and out of the weld quickly and cleanly. This is critical when considering the machining requirements for the lug mount.

Argon shielding and travel speed are critical in the repair of a niobium jet engine heat shield. When heated to welding temperature, niobium wire is sticky like bubblegum, so the welder must carefully slip it right into the center of the puddle. This is where the welder's skill is important, beyond just reading voltage and amperage. Also with niobium, if the metal isn't clean, the puddle doesn't flow as quickly, resulting in more heat input. This causes grain growth, which can show up as a defect in the part.

These are just some examples of situations in which the technical expertise of TOC welders is critical. The training and certification required to prepare the welders to handle such applications are equally crucial.

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Note

1. For more information on welding with GTAW inverters, see "Selecting the right tungsten: How your choice affects AC GTAW" in the February 2004 issue of The FABRICATOR®, p. 28.

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Delta's TOC welders use a larger GTAW cup that provides a 1-inch shielding gas envelope for less heat input and distortion. The larger GTAW cup allows the welders to extend their tungsten out as far as 11¼ in. to make welds in hard-to-reach locations.
The future of structural welding

By Marty Rice

January 13, 2004

Like my history of welding article, this article is my small insight into the future of structural welding. Like I said before, if you are a history or English professor—and I'll add math professor to this group after my last miscalculation, pointed out by Ted Neff from Reynolds Engineering & Equipment, Inc.—you might want to stop reading at this point; again, it may not be pretty.

I've written in the past about how welding hasn't changed in 50 years, yet welding has changed big-time in the last 50 years. The reason this seemingly contradictory statement is true is that there are so many different welding processes. Some have remained virtually the same, such as stick welding, with minor modifications and improvements, while other processes continue to be invented or improved, such as laser, friction-stir, and plastic welding.

2004

OK, so I'm driving by this high-rise, and I see a guy sitting on a beam about 20 stories high. He's looking out at the horizon with a cig hanging out of his mouth, and a smile on his face. It's payday Friday, an hour away from quittin' time, and he has a ringer coming.

He's been stick welding stiffener plates using 7018 low-hydrogen rods. As soon as he throws his tool belt into the gang box, he'll be hauling down 20 flights of stairs in about 20 seconds. He'll jump in his truck, stop and grab a six-pack, go home, take a well-deserved hot shower, and then take his wife out for a big ol' steak dinner.

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Now let's flash forward about 200 years. My great-great-great-great- (you get the point) grandson looks up out of his future-mobile pickup truck and sees a welder about 20 stories high. She's (yep, there are a lot more women welding in the future also) sitting on a beam on a 500-story high-rise. (Buildings get taller as real estate prices skyrocket in the future.)

It's payday Thursday, and she's looking out at the horizon with a cig hanging out of her mouth (yep, people are still smoking!) and a smile on her face. It's an hour away from quittin' time, and she has a ringer coming.

She's been stick welding stiffener plates using 7018 low-hydrogen rods. As soon as she throws her tool belt into the gang box, she'll be hauling down 20 flights of stairs in about 20 seconds. She'll jump in her future-mobile pickup truck, stop and grab a bottle of wine (she doesn't do beer), go home, take a well-deserved hot shower, and then take her husband out for a big ol' steak dinner.

What About Robots?
Hey, wait a minute; this is the future, yet it isn't much different from the past. That's right, welding on high-rises ain't gonna change that much at all! I don't foresee anyone building a robot or machine that will climb around a building like a crazy ol' ironworker will.

Even if a robot could be engineered and programmed, there are just too many variables to consider—misaligned beams, too short or too long beams with holes not aligned with the gusset plates, etc. I don't give a dang how advanced we get, we can't program a machine to fix all the crazy problems a welder runs into on the job.

Now maybe I'm being too pessimistic about our future technology, but you have to realize what my generation was told. I was told in sixth grade that I'd be flying around in a magnetic car by now. I was also told that robots were going to take over all manual work. Heck, I remember hearing adults talking about how bad it was going to be with the loss of jobs, and that we'd all be in the poorhouse because of those dangfangled new machines. They said they might even get too smart and take over the world. Man, that scared the heck out of me! I pictured robots patrolling the streets looking for mischievous little kids like me to take to their robot jails.

Well, sure enough, a lot of technology has been "robotized," especially in the welding field. But I'd venture a guess that it is a very small percentage of the entire industry. And even with robots, a human must program, quality control check, maintain, and repair them.

I spoke with an engineer who said he preferred someone who had worked as a welder to program his robotic welding machine. Experienced welders have the feel for it and do a much better job of setting the programs correctly.

I'm sure there will be some improvements in structural welding, such as better welding machines, maybe a little more stable arc, and probably more flux-cored welding, but in my opinion, welding isn't going to change that much. It'll still be the basics of relaxing your hand; watching the puddle; and using the right travel speed, rod angle, and temperature.

**Get the Lead out of the Way!**

Maybe someone will invent a way to stick weld without having to drag hundreds of feet of that welding lead around. Wouldn't that be nice? That welding lead will hang up on anything. I literally fell off a three-story building once when my lead tangled up as I was walking a beam on the outside perimeter. Lucky for me, I landed on a scaffold just a few feet below. I noticed that some guys had seen me fall and were freaking out. I climbed back up, dusted myself off, and hollered, "I hate it when that happens!" After they figured out I hadn't really gone in the hole, they waved to me, but for some reason used only one finger.

They say you can jump out of an airplane with a section of welding lead on your shoulder and never hit the ground... it'd tangle up someplace!

**Will the Jobs Be There?**

No matter what job you're in these days, you're probably wondering about its future. According to the U.S. Department of Labor Bureau of Labor Statistics (BLS) *Occupational Outlook Handbook*, the future for welding jobs looks promising but will fluctuate as industries prosper or suffer:

"Job prospects should be excellent for skilled candidates, as many potential entrants who have the educational and personal qualifications to acquire the necessary skills may prefer to attend college or may prefer work that has more comfortable working conditions. Employment of welding, soldering, and brazing workers is expected to grow about as fast as the average for all occupations over the 2000-2010 period. In addition, many openings will arise as workers retire or leave the occupation for other reasons."
The major factor affecting employment of welders is the health of the industries in which they work. Because almost every manufacturing industry uses welding at some stage of manufacturing or in the repair and maintenance of equipment, a strong economy will keep demand for welders high. A downturn affecting industries such as auto manufacturing, construction, or petroleum, however, would have a negative impact on the employment of welders in those areas, and could cause some layoffs. Levels of government funding for infrastructure repairs and improvements also are expected to be an important determinant of the future number of welding jobs."

What About the Money?

The BLS reported that the median hourly wage of welding, soldering, and brazing machine setters, operators, and tenders was $13.09 in 2000. The middle 50 percent earned between $10.41 and $16.83. The lowest 10 percent had wages of less than $8.64, while the top 10 percent earned over $23.32.

Median hourly wages in the industries employing the largest numbers of welding machine operators in 2000 were:

- Motor vehicles and equipment: $16.16
- Construction and related machinery: $13.72
- Fabricated structural metal products: $12.77

Compare these wages to the median hourly wage for all occupations of $13.31 in the same time period as reported by the BLS. Considering I started out making a whopping $4.50 an hour back in the olden days, these wages aren't half bad!

No way can I predict how high wages will be 200 years from now. If I could do that, I'd be making a killing in the stock market. Oh, I could make a guess, but none of us reading this would be around to see if I was right! One thing I'd bet the bank on is that welding will be around, and it still will be a matter of relaxing your hand; watching the puddle; and using the right travel speed, rod angle, and temperature.

1. A ringer is a 40-hour paycheck. You don't want to mess up your 40-hour paycheck by missing any work.

2. Stiffener plates are put at various points of a beam to give it more strength and keep it from sagging. Everything on a high-rise is about load bearing. Columns distribute the building's weight to the ground. Beams take weight to the columns. A stiffener plate fits into the web of the beam vertically and beefs it up, which means you can use a thinner beam to carry the same load as a thicker, heavier beam. Add up all the beams in a high-rise and that makes a lot of difference both weightwise and moneywise. And when it comes to construction, it's all about the money, grasshopper!

3. In the future people have finally realized that the 40-hour workweek should be changed to 24 hours. Fridays are the beginning of a three-day weekend, and Mondays are off because, well, it's MONDAY!

4. Going in the "hole" is ironworker slang for falling off a building. Every year workers are badly hurt or killed going in the hole. It is one of the inherent dangers of working high steel.
GUIDE

SERVICES - AFLOAT - PIPE FABRICATION SERVICE

POST AN ENQUIRY

The pipe fabrication facility offers a specialized service mainly for the repair, fabrication, and installation of marine pipe work.

Golten offers

- Experienced pipe fabricators and supervisors
- Licensed welders with highest class for X-Ray pipe joints, Low Temperature Steel and Stainless Steel Pipe fabrication
- Complete range of pipe fabrication equipments
- Agents for G.S. Hydro

Parts that generally need attention

- Cargo Manifolds
- Deck Pipelines, IG, Cargo, Fire Foam Lines
- Pump Room Pipes
- Steam Piping
- Heating Coils
- High Pressure testing
- High Pressure Hydraulic Lines

Problems most often observed

- Leaking Pipe Joints
- Corroded and Wasted Pipe Lines
- Retrofits to OCIMF recommendations.