Welding Aircraft Stainless

How-To with GTAW and OFW

KENT WHITE

CAN YOU NAME THREE AIRCRAFT constructed mostly of stainless steel? If you said the Fleetwings Seabird, Bell X-2, and XB-70 Valkyrie, you copied the right frequency. The weight savings with stainless are salient. By not using rivets the Seabird saved 267 pounds, and the strength/weight ratio of full-hard *18-8* is considerably higher than high-strength aluminums. Remember, too, that once the spot welders (or "shot" welders) are set for action, they can move at a very rapid pace and make a very strong weld. And, yes, this family of 18-8 *chromium-nickel stainless steels* does not mind the occasional shower of salt spray.

First specified in 1926, austenitic chromium-nickel stainless steels are often abbreviated as "Cr-Ni stainless." The group comprised of types 301, 302, 304, and 305 is often referred to as "18-8" because these types contain roughly 18 percent chromium and 8 percent nickel. Type 316, stabilized with molybdenum, is 18-8-Mo, type 321 with titanium is 18-8-Ti, type 347 with columbium is 18-8-Co, and type 303 is known as "free-machining 18-8." Stabilization is the ability of the particular alloy to hold carbides in solution, preventing their precipitation in solid form. During hot-working conditions such as annealing, welding, or stress relief, this is important because it allows the 18-8 to remain workable and resist *stress-cracking*.

Not limited to just exotic and unusual construction, these corrosion-resisting steels are routinely found in aircraft firewall construction, tanks, and exhaust stacks—applications that involve stress and require high strength-to-weight ratios. In specialized environments of high stress, high heat, and high corrosion, like engine exhausts, we might find alloy 321 or another "stainless" alloy—Inconel. Comprised of roughly 45 to 80 percent nickel and up to 19 percent chrome, Inconel alloys are in the family of *heat-resisting alloys* and have the ability to retain high strength at elevated temperatures (70 ksi yield at 1,200°F).

Key Words

Carbide Precipitation

Stabilization

Passivation

In prop-driven fighter planes, the vast majority of 18-8 and Inconel exhaust collectors were gas welded with oxyacetylene, using special welding fluxes designed for the particular alloy, along with the correct filler rod. Nowadays, TIG welding (GTAW) has replaced the OFW, but we'll cover both processes, and will discuss the methods for both new construction and for repairs and restorations.

New Construction

When the tubing, flanges, and fittings are new, things are pretty straightforward. Cut and fit all the parts so there are no gaps, jig the parts to hold them in alignment, and tack them together. Remember that prior to welding you must first solvent wash (70 percent denatured

A P-38 NOS exhaust duct using OFW construction, lightly sandblasted, then passivated.

To GTAW tack .030-inch sheet without filler requires less than 50 amps DC, a shade 8 or 9 lens, good vision, and steady hands.

alcohol is good) and abrade the joints to a bright finish with sandpaper before blowing them clean with compressed air to remove spent grit.

Set the GTAW machine to DC and to a slightly lower current setting than for mild steel of the same thickness. Sharpen tungsten to a 90-degree point and clean the filler (if it's to be used). If you're not using a construction and welding jig, once all pieces are tacked on quarters (tacking at 90 degree points around the circumference), check their alignment by fitting the part to the assembly jig or mounting the assembly on the engine.

You can remedy small discrepancies by nicking a few tack welds and refitting or by using hot-working methods. Because torch-applied annealing and stress relief is legal, heating the 18-8 to either a blue heat or up to the measured 1,950° F and bending or tapping the part into confirmation will suffice. Reclean all joints back to bright (never use ferrous or plain steel brushes!) and then *slowly* and carefully weld completely.

Fillers

The common filler for 18-8 is 308, although you may use 309 for applications requiring higher ductility. Filler diameter should be about equal to metal thickness, but if the joint is perfectly tight and uniform, *no filler is necessary*. This I learned from Nick Lorenz, owner of Plenetics Corp. in Southern California, contractors for welded stainless assemblies on the F-16. Inconel alloys, however, sometimes do require fillers.

The Root Side

As with aluminum welding, the root side of nickel alloy may need special attention if appearance or gas flow is important. The standard argon back purge may be suitable, albeit expensive if very much is needed. To do this, attach a double-valve Y fitting below the argon regulator and let one side feed a simple open hose. Close one end of the exhaust tube with a rubber plug or a rubber flap cinched by a hose clamp, and then seal the argon hose through it. Tape a diaphragm over the other end and make a small pinhole in its center. Crack the valve just enough so the diaphragm bulges, indicating a slight positive pressure within the tube, and then weld'er up.

Without back purge, consider the method high-end race-engine builders widely use: paint a special GTAW *backup flux* on the inside surface of the tube ends before tacking and welding, leaving a smooth root side free of "sugar," thus enabling a smooth flow of exhaust gas. This flux may take only a hot water wash to clean out because it's water-soluble and noncorrosive to stainless.

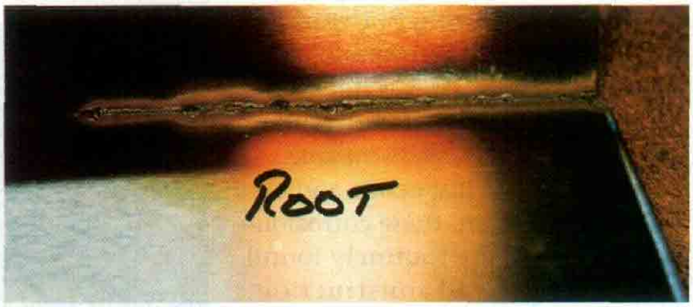
Repairs

I hear from a number of maintenance welders around the country who have had lousy experiences welding old exhausts, and some have confessed to me that they (cover your ears) use mild steel rod or even (Lord have mercy) coat hangers! I know it's "just a Mooney" or whatever, but I never have the heart to ask what the "repair" looked like after 30 hours.

Taking a whack at a solitary crack with just the nearby torch is tempting. The drawback to GTAW is that dirty old pipes don't like to melt in and flow real nice, so the welding experts say, "Get a new one, and throw that old one away!" You can't get the backup flux to help you out in this pinch, so what can one do when it's just one simple crack, and so obvious at that?

Oldtime OFW

Commonly used until the 1950s to weld stainless, Inconel, Monel, and other aircraft metals, the oxyacetylene torch requires low pressure settings at the regulators (2 to 4 psi each), and perhaps a slightly smaller tip than used for other steels, because stainless doesn't conduct heat well at all. The typical thicknesses encountered will run from .049 to .065 inch, so many manufacturers' tips



Working the puddle with the arc enables better flow across the gap. Dunk the tungsten and the elegance halts, until you grind it clean again. *The root is typical.*

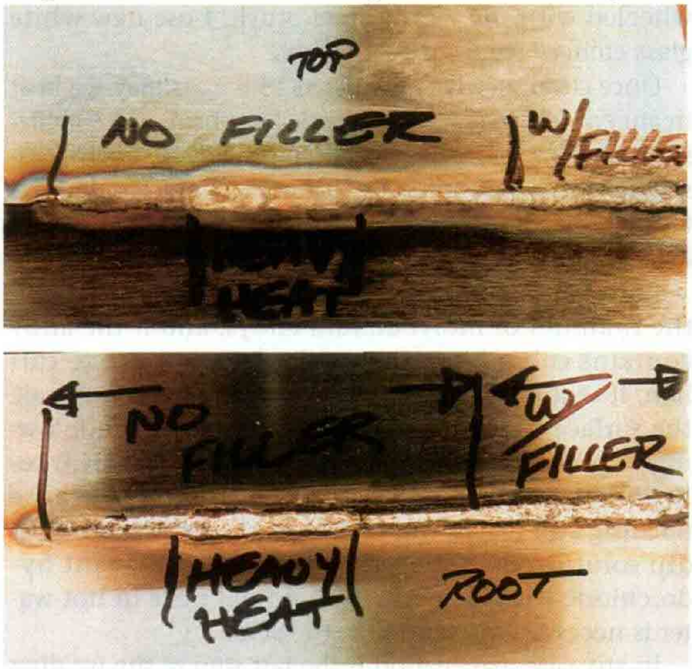
of .028- to .035- inch diameters will do nicely.

You *must* use a flux! Select a special stainless gas welding flux (or Inconel flux for that alloy) and mix it with 70 percent denatured alcohol. Let flux stand for a minute or three and make sure it's thoroughly mixed. Remember that iron contamination from common (not stainless) steel brushes or rubbing against steel workbenches will cause surface rust or intergranular corrosion on stainless, so take precautions.

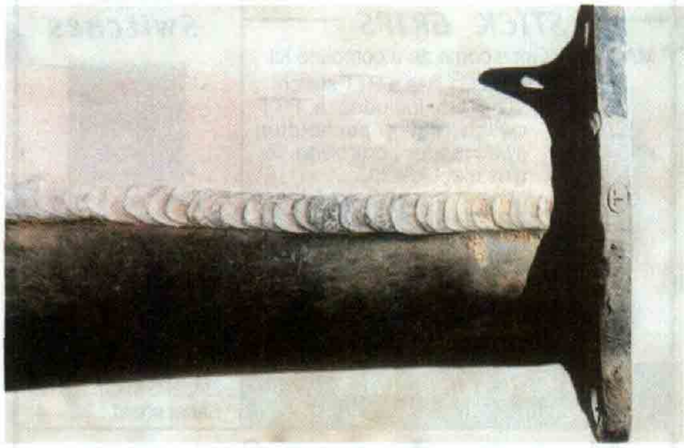
If needed, choose a filler diameter equal to metal thickness and with a higher chromium content than the material to be welded, because chromium is lost to chromium-oxide formation in this welding process. Fillers listed by increasing chromium content are 308, 309, and 316. L, as in 316L, means low carbon content, and is preferable. After using the cleaning methods mentioned previously, flux the filler and, if possible, both sides of the material. If not possible, brush flux vigorously *across the crack* to force it through and onto the backside.

Method

Setting the flame dead neutral, or if the regulators creep, with a slight feather (carburizing, carbonizing, reducing, or for you carburetor guys: rich), tack normally, using a periodic thunk with a hammer to keep the mating surfaces aligned. Even a slightly carburizing flame will raise the carbon content of the deposited filler about 15 points, adding slightly to hardness and brittleness, and reducing corrosion resistance somewhat. Avoid full reducing flames because they could increase carbon by 60 points, and avoid oxidizing flames because of poros-



Using a filler helps fill the inevitable hole. The backup flux certainly improves penetration and appearance and makes welding a lot easier because holes don't blow nearly as easily.



An old Wright collector ring welded with and without backup flux. Note the "sweat" on the top side of the flux weld. The root shows heavy "sugar" on the left side (I used filler on this weld), and on the right the flux cleans off leaving a bright finish. (No trick photography, just a graphic difference.)

Rasty old exhaust tube gets the treatment: the saw kerf is welded using both methods.

ity, spitting, and incomplete fusion.

As you work, shield both the puddle and the end of the filler with the torch flame, being careful not to stir or agitate the molten puddle as you add the filler. My technique is to keep the rod engaged in the puddle while melting the puddle *into* it, fusing the sides together and combining the rod all at the same time. Stainless is sluggish to weld, so you can "push" on it with the torch flame for better penetration.

Carbide Precipitation

As the temperature of the just welded 18-8 falls, it passes through the carbide precipitation range of 1,000-1,500° F. If the carbon content is very low (.07 percent) and the time at this temperature is short (less than two to three minutes), these precipitates will not form. But if held in this range for longer than three minutes, and if the parent metal or the filler metal has a carbon content higher than .07 percent, then carbides will form, making the metal hard and brittle. To avoid this, quench heavy thicknesses (greater than .060 inch) with water or use air (less than .060 inch) to hasten the cooling through this range.

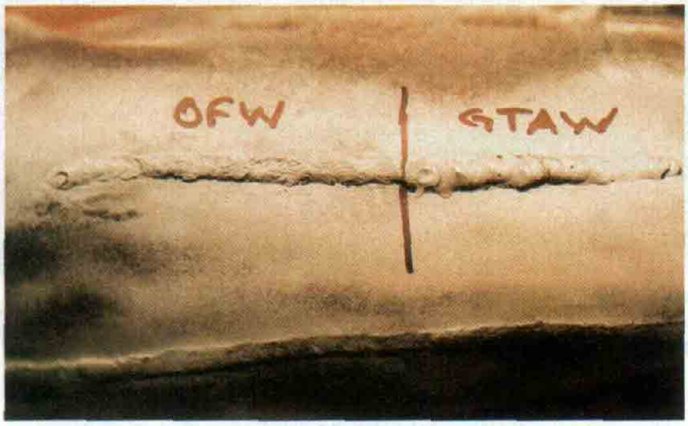
Cleanup

A good abrasive like a rotary mesh wheel will scour the surface bright without loss of metal thickness. If you sandblast, use a fine grit free of rust or any mild steel particles because those particles will embed themselves in the surface, allowing rust and corrosion to proceed. If you ever have a close look at the St. Louis Arch (all stainless), look up about five panels on the left side. There you'll see where a workman wire wheeled with the wrong steel brush! I use new white glass etchers' sand for best results.

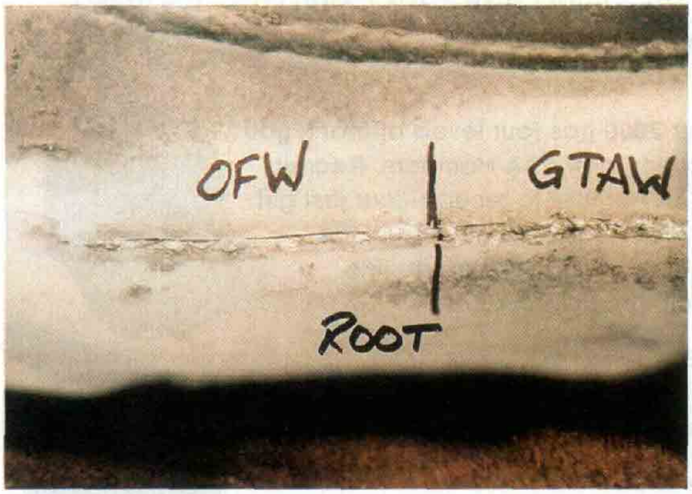
Once clean, newly constructed 18-8 parts may see heat treatment for stress relief, an annealing heat, or a stabilizing treatment before they receive pickling and, finally, *passivation*. If the carbides are known to have formed (by testing), then a stabilizing or annealing treatment is given, depending on the metallurgist's requirements.

Both treatments will dissolve carbide precipitates in the titanium or molybdenum alloys, and if the alloy contains columbium in a ratio of 10 or more to carbon, it requires none. These heat treatments will scale the surface of the metal and require either sandblasting or pickling in a 50 percent hydrochloric (HCl) solution at 130 to 140°F for about an hour. Because pickling still leaves the surface dark, prepare a bright dip solution of 10 percent nitric and 3 percent hydrochloric (HCl) acid at 160°F. A final rinse in hot water is necessary to neutralize the acid.

In any case, passivation is the last step in the welding process of new or repaired parts, and it restores corrosion resistance by dissolving any embedded particles. Immerse the material for 20 minutes in a 15 to 20 percent nitric acid solution at a temperature between 120 and



The sandblasted top side shows that GTAW took a bit more effort to close the gap. For the OFW I used a "fuzzy" coned flame and a .028-inch tip, but after seeing the penetration, I would now drill the tip to .030-inch.



The root shows good penetration and some misalignment in the joint. The rubbly penetration of the GTAW indicates a need for backup flux. The only reason you can see the root side here is because I used a plasma cutter to demolish the part! Note the factory OFW weld nearby. Sigh.

150°F. This doesn't affect the surface in any way, so even those parts that have received a high polish earlier need nothing after this process.

If all this makes you want to give up, I can't blame you. The idea of having a corrosion-resistant exhaust system is practical, however, and seeing the abundance of high-time (60 years?) units out there is proof that the time and effort are well spent. The Russians build a lot of exhausts on their lightplanes out of titanium, and I just wonder what is involved there . . .

EAA Technical Counselor Kent White achieved Master Technician's status at Harrah's Auto Collection in 1976, where he restored metal components for aircraft and automobiles. He started his own metal restoration company in 1977, and now teaches, writes, and develops tools for metalworking while he still pounds out parts. He encourages any welder or metalworker, man or woman, to contact him in regard to preserving the traditions of aircraft metalworking. To contact White, call 530/292-3504, e-mail www.tinmantech.com, *or regular mail 17167 Salmon Mine Rd., Nevada City, CA 95959-9350.*