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WELDING RESEARCH SUPPLEMENT

Welding Race Cars: NHRA vs. NASCAR Techniques

The methods for welding frames for various race cars are detailed

BY JERRY UTTRACHI

While managing a welding filler material R&D lab in the mid 1970s, a company that built drag race car frames and sold tubing kits to customers fabricating their own chassis asked for a recommendation for a gas tungsten arc welding (GTAW) rod for joining normalized 4130 tubing without preheat. Before making a recommendation, options were discussed with several of our engineers and metallurgists to define the best welding rod to join this relatively high-carbon material without preheat.

Drag Racing Chassis

After considering that 4130 is a chrome-moly steel, with the dilution into the high-carbon base material (high by welding standards) without preheat, we concluded that a filler metal that would reduce the risk of cracking was best, and a low-carbon ER70S-2 filler rod would be optimum. We knew that even in an undiluted AWS filler metal electrode test, a weld made with GTAW and ER70-S2 has a higher strength than if made with gas metal arc welding (GMAW). The weld beads are generally smaller than when welding with GMAW, and it uses 100% argon shielding gas that oxidizes less carbon and alloy elements. A typical all-weld-metal tensile from an undiluted GTA weld deposit made with ER70-S2 produces 565 MPa (82 ksi) tensile strength with 31% elongation. The GTA welds also have low inclusions and produce 230 joules (170 ft-lb) at −29°C (−20°F) CVN. Even when diluted into 4130, we estimated a single-pass GMA weld would provide a slight undermatch to normalized 4130 but because most welds were fillets, a slightly large size could compensate. The chassis manufacturer was given our recommendation. A year later, their product catalog offered ER70-S2 GTAW rods for sale.

Some believe they should weld with an AWS ER80S-D2 moly-containing rod. However, the ER80S-D2 alloy rod has 0.50% moly while 4130 has only 0.19% moly. It also has 3.5 times the manganese but no chrome. Using an estimate of hardenability in a GTA weld deposit in 4130 comprising a 30% weld rod, the remainder melted base metal yields an interesting result. A good measure of hardenability is called critical diameter — Fig. 1. It is the diameter of a round bar that, when heated and quenched, has 50% martensite in the center. The larger the bar diameter where 50% is found, the more hardenable. A method defined by Crafts and Lamont was used to estimate this parameter from the chemical composition (Ref. 1).

The critical diameter of 4130 base material is 60 mm. A weld made with AWS ER70-S2 in 4130 has a critical diameter of 53 mm or a 12% undermatch; however, when 4130 is welded with an ER80S-D2, it is 84 mm, which is a 40% overmatch. That deposit would be more susceptible to cracking depending on the specific joint and stress.

Fusion Weld and 30% Dilution With Filler Metal

Element	4130 No Filler	AWS 80S-D2	AWS 70S-2
Carbon	0.33	0.26	0.24
Manganese	0.53	0.93	0.72
Silicon	0.05	0.23	0.18
Moly	0.18	0.28	0.13
Chrome	0.90	0.63	0.63
Structure	Martensite	Some Martensite	Little Martensite
Critical Diameter	60 mm	84 mm	53 mm
Crack Potential	High	High to Moderate	Moderate

Fig. 1 — Crafts and Lamont define a way to estimate a measure of steel hardenability using the chemical composition. An AWS ER70-S2 electrode provides a slight weld strength undermatch, but a moly-containing AWS ER80S-D2 electrode has an excessive 40% overmatch.

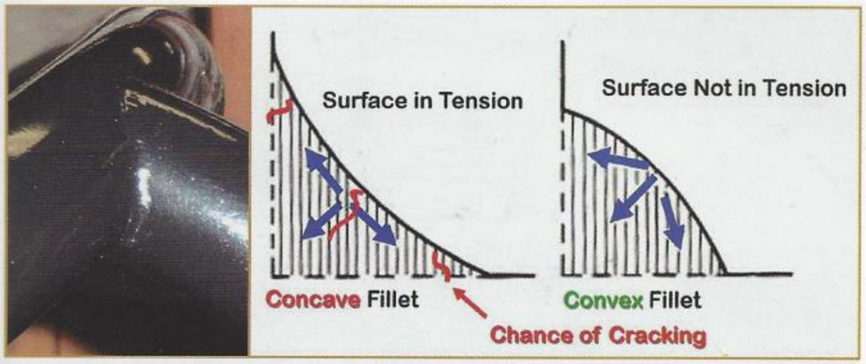

Fig. 2 — Although a concave fillet has a smooth intersecting angle, when cooling, the weld shrinks and the tension created across can cause cracking. A flat to convex bead is best.

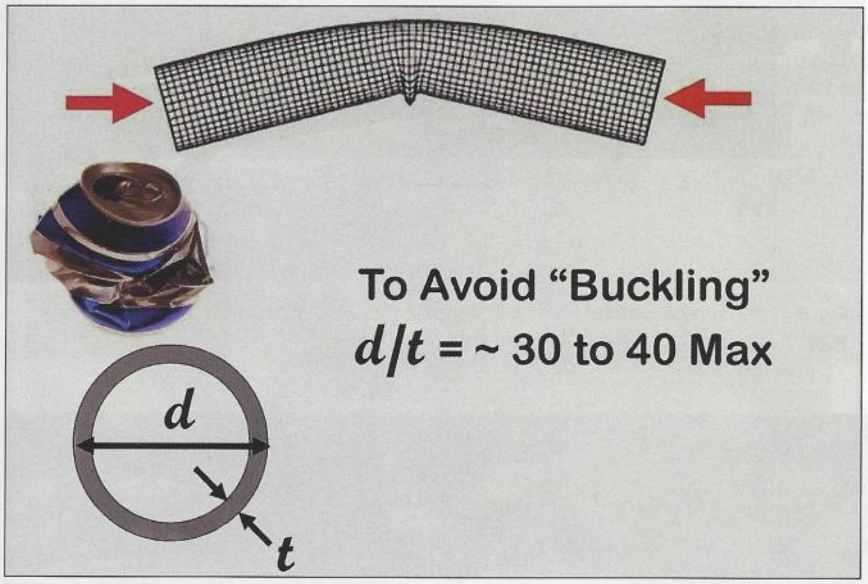

Fig. 3 — If high strength is used to enable a thinner tube wall thickness for lightness, it can cause a phenomenon called "local buckling." If placed in compression, that can cause the tube to bend well before the maximum column strength limit. A minimum diameter to wall thickness ratio of 30 to 1 should be observed as a precaution.

Fig. 4 — This unique frame support was observed in a dragster chassis using heat-treated 4130. It appears to be designed to limit movement of the frame components to prevent local buckling. A dragster does not use springs; the chassis flexing provides the needed suspension.

Many fabricators successfully use ER70-S2 for GTAW normalized 4130 tubing without preheat or postweld heat treatment.

Filler metal selection is the first step, but making quality welds is also required. Unfortunately, drag race cars are often observed with very concave fillets. They look nicely contoured and fared into the base material, but they are not as strong as flat to convex welds. The low angle these welds make with the base material may appear ideal, but they are more susceptible to cracks as the welds cool. They should be flat, so it is best to err on the convex side. Figure 2 shows a weld from a dragster roll bar taken at a recent national race at the Charlotte zMAX Dragway. The welder may have believed a wet-in shape would be best, but it would have been stronger if it were flat to convex. There were many welds found in other drag race cars that were similar. The National Hot Rod Association's (NHRA) sanctioning body requires GTAW to be used when welding 4130, and they cannot be ground. We receive a number of questions for information on the subject as to why (Ref. 2). Because the NHRA generally uses a visual inspection of welds, they do not want a poor weld made visually good in appearance with a grinder that prevents a good evaluation especially once painted.

While most professional class drag race car frames are fabricated with normalized 4130 tubing having a typical tensile strength of 670 MPa (97 ksi), some builders believe they can effectively use heat-treated 4130 in parts of dragster frames, which can have a tensile strength exceeding 1040 MPa (150 ksi.) However, its use presents problems from the standpoint of structural design. When welded, the quenched and tempered heat treatment that creates the high strength is eliminated and strength is reduced in the heat-affected zone (HAZ).

As an example, in a drag race shortly after allowing heat-treated 4130, a dragster traveling more than 250 mph caused a crash where the high-strength tubing was allowed. In a subsequent race, it was revealed that the failure was due to local buckling, which is sometimes referred to as the "crushed can effect." If the higher strength is used to employ a thinner wall tube, when under load, it could fail by buckling — Fig. 3. Like the crushed can trick, you cannot push on the ends and cause a can to collapse, but if you put a small dimple in the side with your thumb when pressing from the ends, it caves inward at that point, crushing easily.

Figure 4 shows a unique structural support on a top fuel dragster frame. Note the bottom of the vertical brace is not welded to the lower member.

Was it not welded because the bottom rail was made from heat-treated 4130? Or was it just a mechanical support design to help prevent buckling of the frame rails?

NASCAR Stock Car

Where a top fuel dragster weighs 1050 kg (2300 lb), a NASCAR stock car must weigh 1510 kg (3300 lb). The stock-car racing organization employs a "bend before break" design philosophy and specifies the use of mild steel tubing, as well as the safety cage design and minimum tubing wall thickness. Figure 5 is a typical NASCAR frame during construction. Most welds are made with gas metal arc welding-short circuit arc (GMAW-S). Typically, ER70-S6 or ER70-S7 welding electrodes are employed. These provide a ductile weld deposit with sufficient strength to exceed the base material; however, few if any welds with butt joints are made. Most requirements are for fillet welds to join the many intersecting tubes.

Figure 6 shows a car on display at the Darlington Raceway Museum. It

Fig. 5 — The material of this frame is specified as mild steel. NASCAR dictates the safety cage design, tubing size, and wall thickness.

Fig. 6 — This crashed car is on display at the Darlington Raceway Museum.

Fig. 7 — This top corner of the safety cage was subjected to significant force. The welds are flat to convex and held without failure during the crash.

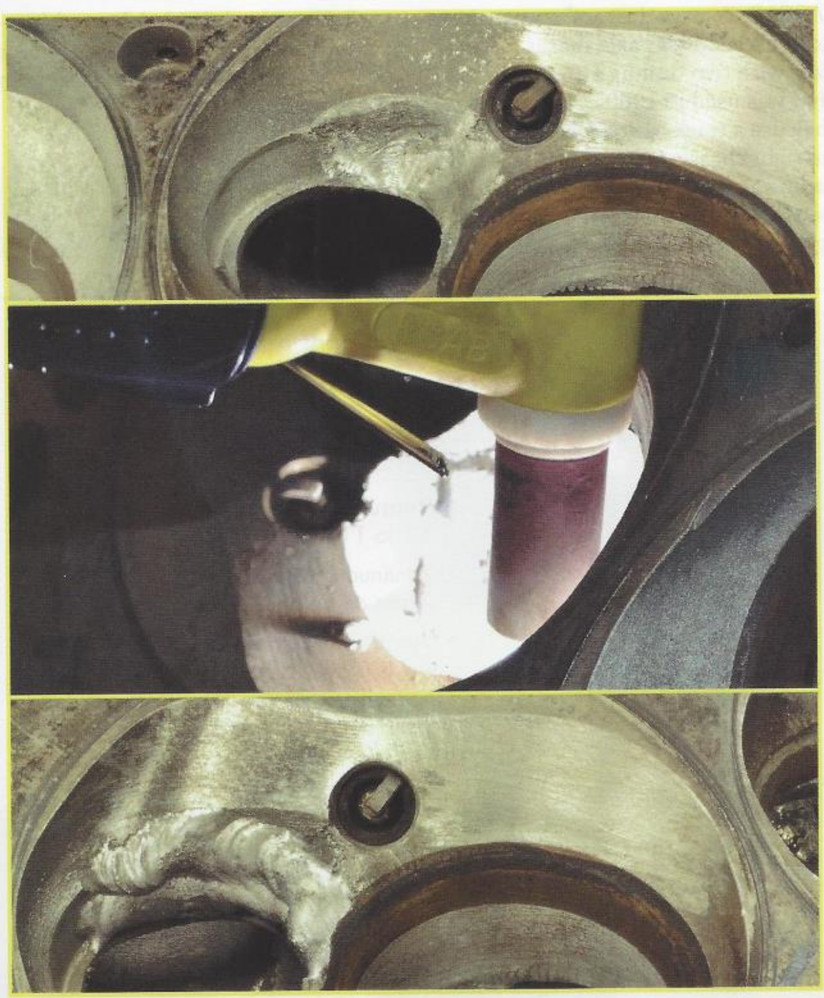

Fig. 8 — Although GMAW is used for most NASCAR construction, there are places where GTAW is employed. One example is repairing cylinder heads for all but the top series cars. When the pounding from the stiff valve springs and high lift cams causes seat distortion, GTA weld beads can be deposited and the area machined to accept new hardened valve seats.

was driven by Darrell Waltrip at the Daytona Speedway and during a crash, it rolled more than ten times. However, Waltrip walked away from the wreck, uninjured, a testament to the "bend before break" design.

Figure 7 shows a section of the top corner of the roll cage that was subjected to the rolling. Note the GMAW-S weld beads are flat or convex, unlike the concave GTA welds employed for some drag racing cars. They all held during the crash. You can also see the use of gussets to strengthen some tubing intersection weld joints.

A question often asked is can 4130 be welded with GMAW? It can. It is used in NASCAR fabrication for some applications. For items like radiator supports, where members are not providing driver safety, higher strength 4130 tubing can be used. As the frame fabricators are using ER70-S6 or ER70-S7 filler metal, they would use those materials and the same GMAW process to join these structural members. That will provide an undermatch but similar to the welds on the main chassis and if more strength were needed, a slightly larger fillet weld could be used. With the typical 75% argon, 25% carbon dioxide shielding gas mixture employed with GMAW compared to the 100% argon used for GTAW, more of the manganese and silicon alloying elements in these mild steel wires will be oxidized. In addition, there is generally a higher percentage of the mild steel filler material and less of the higher strength 4130 in the weld deposit. This should be considered in the design and, as mentioned, a larger size fillet used if necessary.

If making butt-joint welds, it would be best to use GTAW and ensure complete joint penetration. Simple butt-joint welds in tubing are not common because it is easier for fabricators to select a longer length to start.

Repair of aluminum cylinder heads is another application where GTAW is used in NASCAR. Typically for the top Monster Energy series cars, new parts are employed; for the lower series, cost is very important. Weld repair of valve seats can save significant money for the custom-modified cylinder heads.

Figure 8 shows a sequence typical of a cylinder head repair. The top shows the cylinder head with the hardened valve seat insert removed and any worn or cracked area removed through grinding. Because the cylinder head is thick, preheat is usually employed to ensure sound, well-wet weld beads. One shop uses a large propane-fired barbeque rather than an expensive furnace to heat the head from 150° to 175°C (300° to 350°F) prior to welding. Details of the weld repair are presented in Refs. 3 and 4.

Filler metal selection is usually a silicon alloy, such as AWS ER4043, or a higher silicon, such as the AWS ER4145 weld rod. These alloys provide satisfactory performance in this high-temperature service. The high lift cams and very stiff valve springs employed in a high-power engine cause distortion in the valve seat area after a relatively few miles compared to a passenger car engine. After GTA weld beads are made, the valve seat area is machined prior to pressing in hardened inserts.

Gas tungsten arc welding may also be used for parts such as suspension members and rear axle assemblies. NASCAR dictates the cars' suspension include a solid rear axle that is held in place with two trailing arms similar to what was used in 1960s Chevy trucks. They use a track bar that bolts from the right chassis frame to the left-side trailing arm. The front suspension specified is similar to an old Ford design. However, some teams find ways within the rules to make changes to give a racing advantage.

What are designed to be very rigid assemblies by controlling gaps can be allowed to move slightly in a turn to provide a small speed advantage. Small weld deposits placed in critical areas, even an autogenous GTAW bead on some differential gears, can be used to alter the intended way the components behave under certain loads. Some of these adjustments are considered illegal and can result in significant fines, if found. WJ

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Earlier Article published in the Welding Journal Based on Training at Richard Petty's Facility in Level Cross NC Where We (L-TEC Welding & Cutting than Became ESAB Welding & Cutting Products) Were Sponsors for Over 15 Years

NASCAR Race Team Demands Quality Welds

Race car fabricators learn some key points about processes and selecting filler metals

By JERRY UTTRACHI [AWS Welding Journal, April 2003; 84(4):pp104-106: text only; copy of actual paper follows BUT because of background color difficult to read]

Race cars require hundreds of welds. Most welds join intersecting tubes that make up the frame and the all- important roll cage. NASCAR chassis are unique in racing circles. The cars have a minimum weight of 1542 kg (3400 lb), quite heavy by race car standards. NASCAR requires the frame and roll cage components be fabricated from mild steel. This allows the car to absorb the forces of a crash in a bend-before-break mode. Although the driver cannot be protected from every incident, considering the number of high-speed crashes encountered in NASCAR races, the drivers most often walk away unhurt. This is a tribute to the chassis design and the weld quality.

In addition to the main chassis members, some welds are made in 4130 chrome moly (molybdenum) tubing used for such things as radiator supports. Suspension and steering components must also be welded. Using the proper welding process and filler metals is very important to ensure superior quality.

ESAB Welding and Cutting Products, Florence, S.C., recently provided welding training to Petty Enterprises at its Level Cross, S.C., facility. Below are some key points Bob Bitzky, an ESAB welding engineer with 25 years of experience in the welding industry, outlined for the team fabricators.

Pick the Process

The first consideration for mild steel welding, which is the predominant material joined, is deciding what welding process to use. Shielded metal arc (SMA), gas tungsten arc (GTA), or gas metal arc (GMA) welding are the three processes usually considered. Shielded metal arc welding offers few benefits for in-shop use. The process presents slag removal and possible slag entrapment issues. Gas tungsten arc welding can produce excellent quality welds but so can gas metal arc welding. For the majority of the fillet welds required, GMA welding is faster and may produce less heat input for lower distortion. This process also makes it easier to produce consistent-quality welds. There is a misconception in the race car and street rod circles that GMA welding is not usable for critical welds. In fact, the GMAW process is used extensively in industry to make very high-quality, critical welds in items such as submarine hulls. Submarine hulls are made from high-strength steel and are predominantly welded with the GMAW process. Pulsed gas metal arc welding (GMAW-P) can provide welds without any spatter, similar to GTA welding, as well as a controllable, hot arc to ensure the weld is fused to the base metal. Short circuit GMA welding (GMAW-S) is most often used on thinner materials such as tubing and provides excellent quality in the hands of a skilled welder.

Select the Proper Filler Metals

Selecting the proper filler metal requires an understanding of the mechanical properties desired and weld appearance considerations. Table 1 presents the chemical composition of typical mild steel tubing and several welding wires that can be used to join it.

As seen in the table, to achieve the required strength, welding wires contain less carbon than the base material and more of the alloying elements, manganese and silicon. These differences, and low levels of impurities in the welding wire, help provide crack-free and porosity-free welds. Note that the manganese-to-silicon ratio in ER70S-7 is significantly higher than ER70S-3 or ER70S-6. This higher ratio gives weld bead wetting and makes it easier to produce undercut-free welds. ER 70S-7 is the preferred alloy for welding mild steel. As noted, in general, the welds will be at least as strong as the mild steel tubing.

Maintaining Welding Parameters

After selecting the welding process and filler metal, the proper welding parameters must be maintained. Wire feed speed, voltage, and travel speed are the key parameters to set and maintain. Welding current is a dependent variable and is controlled by wire feed speed and electrode extension. This extension is a critical variable. This is the distance from the end of the welding gun contact tip to the workpiece. In tight confines, it may be desirable to use a longer contact tip to ensure this value does not exceed about 1Ú2 in. If the electrode extension becomes excessive, welding current will automatically reduce, resulting in a colder weld with reduced penetration into the base metal. It is important to keep the arc on the leading edge of the weld pool to assure proper tie-in to the base material.

Special Cases

Problems encountered can often be fixed. For example, a small weld made on a heavy steel part cracked immediately after welding. The cause was attributed to the very high restraint being placed on the small weld bead. Also, a high-strength stainless steel alloy was used as the filler metal, which further stressed the weld joint. The solution was to use a lower strength carbon steel filler metal and a larger, more convex weld bead.

In another case, a crack occurred when welding on a small threaded part. A chemical analysis performed on the part indicated it was made from free-machining steel. This particular alloy used a high sulfur content to aid the machinability. Some free-machine alloys also use additions of lead or phosphorous. High sulfur, phosphorous, or lead additions can only lead to poor quality welds. The solution for this application is simply to not weld free-machining steels. The machine shop should pick another alloy.

Summary

Selecting the proper process is the first task of ensuring quality welds. Gas metal arc welding can be used very effectively to achieve the desired results. Picking the proper filler metal is also critical. An AWS ER70S-7 welding wire is a good choice for welding mild steel. For GMAW, selecting and maintaining the proper welding voltage, wire feed speed, and electrode extension are very important to achieving quality welds. The resulting welds should be checked and verified to be sure they meet the requirements. As a minimum, all welds should be visually inspected for undercut and smooth transition to base metal. When satisfactory welds are produced, record the machine settings for future reference.

What about Welding 4130?

In the mid 1970s, while managing an R&D group for a welding filler metals manufacturer, I received a phone call from a dragster chassis builder. The company wanted to weld 4130 tubing and needed a filler metal recommendation. After careful review of the requirements and desired welding practices, the solution was defined. The company was welding 4130 normalized tubing. It would not be heat-treated after welding, and preheat was not desirable. Most of the weld joints were intersecting tubes that required fillet welds.

Filler Metal Choice

The main objective was to produce porosity- and crack-free weld deposits. The best filler material to use was a low-carbon alloy, AWS ER70S-2. This welding alloy has a very low carbon content, nominally 0.06, which can handle dilution into the relatively high (in terms of weld metal) 0.30 carbon in the 4130. The resulting diluted weld deposit has a tensile strength of approximately 590 to 620 MPa (85,000 to 90,000 lb/in.2) The actual strength will depend on the amount of dilution with the 4130, weld bead size, and material thickness. This is usually an under match for the 4130 tubing, which could have 760 to 800 MPa (100,000 to 115,000 lb/in.2) tensile strength, depending on how the material was processed. However, if extra joint strength is required, a slightly larger fillet size or gussets can be employed. In addition, this welding wire contains small amounts of aluminum, titanium, and zirconium. Although these elements were initially added to handle welding over mill scale, they also contribute to a less fluid weld pool. The benefit to the welder is easier out-of-position welding. Note: It is recommended all welding on 4130 be performed on ground surfaces free of oil or grease.

Several years after making this recommendation, when looking at a catalog from the dragster chassis manufacturer, it was interesting to note it advertising its use of the ER70S-2 filler metal for their 4130 welding. In fact, offering it for sale for those customers purchasing frame parts and doing their own welding!

The Internet was searched to see what current recommendations were being made for joining 4130 tubing. Several hundred sites were found that recommend the ER70S-2 welding wire alloy. It was the predominant recommendation. Typical of the Internet, however, there were many improper descriptions of why this alloy should be used and several incorrect recommendations.

Go for Higher Strength

If a higher strength weld is required for perhaps a butt-joint weld that cannot be reinforced, strengthened with a gusset, or put in a less critically stressed area, there are several possible solutions. The use of AWS ER80S-D2, which contains 0.50 moly, will provide a weld deposit with higher strength. When diluted into the 4130 base material, a weld tensile level of 760 to 800 MPa (110,000 to 115,000 lb/in.2) can be achieved. If this higher strength welding wire is employed, a minimum preheat of 65¡C (150¡F) is recommended. It is also possible to use an AWS ER312 stainless steel welding wire. Weld strength can increase to a level slightly higher than with AWS ER80S-D2.

Generally, the use of this high chrome stainless alloy is only needed when welding stainless to steel. Do not use an austenitic stainless steel such as an ER308L, which is, unfortunately, sometimes recommended. Diluting this or similar austenitic stainless alloys with 4130 can lead to cracks. Also, consider that providing a higher strength weld deposit cannot compensate for the reduction in strength that will most likely occur in the base metal immediately next to the weld deposit. To achieve the higher strength, the base metal was heat-treated, reducing the weld heat-affected zone area hardness.

If the part is heat-treated after welding to achieve very high strength, a matching chemistry filler metal to the 4130 must be employed. Because of the relatively high carbon content, a minimum of 200¡C, (400¡F) preheat and very slow cooling after welding should be used to avoid cracking. After welding, the part can be heated to 870¡C (1600¡F), quenched in oil or water then tempered back to 370¡C (700¡F). This might be considered a complex cycle, but it will result in a tensile strength of approximately 1380 MPa (200,000 lb/in.2). Since the weld is the same chemistry as the base metal, it and the heat-affected zone will have properties similar to the base metal when heat-treated. All critical welds of this type should be inspected for internal soundness to assure they are free from cracks.

Closing Advice
When welding 4130 chrome moly in the normalized condition, AWS ER70S-2 filler metal, with its low carbon content; is the proper choice. If the part is to be heat-treated after welding, then a filler metal matching the 4130 chemistry should be employed. This requires preheat and special precautions to avoid cracking.

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As seen in the table, to achieve the required strength, welding wires contain less carbon than the base material and more of the alloying elements, manganese and silicon. These differences, and low levels of impurities in the welding wire, help provide crack-free and porosity-free welds. Note that the manganese-to-silicon ratio in ER70S-7 is significantly higher than ER70S-3 or ER70S-6. This higher ratio gives weld bead wetting and makes it easier to produce undercut-free welds. ER 70S-7 is the preferred alloy for welding mild steel. As noted, in general, the welds will be at least as strong as the mild steel tubing.

Maintaining Welding Parameters

After selecting the welding process and filler metal, the proper welding parameters must be maintained. Wire feed speed, voltage, and travel speed are the key parameters to set and maintain. Welding current is a dependent variable and is controlled by wire feed speed and electrode extension. This extension is a critical variable. This is the distance from the end of the welding gun contact tip to the workpiece. In tight confines, it may be desirable to use a longer contact tip to ensure this value does not exceed about ½ in. If the electrode extension becomes excessive, welding current will automatically reduce, resulting in a colder weld with re-

Table 1 — Typical Chemical Compositions and Properties of Mild Steel Tubing and Welding Wire

Chemical Element/ Strength	Typical Mild Steel Tubing	AWS ER70S-3	AWS ER70S-6	AWS ER70S-7
Carbon	0.15 to 0.18	0.08	0.08	0.08
Manganese	0.80	1.15	1.50	1.65
Silicon	0.15	0.60	0.86	0.60
Ratio Manganese/ Silicon	Not Applicable	1.9:1	1.8:1	2.75:1
Tensile Strength	450 MPa (65,000 lb/in.^{2})	520 MPa (75,000 lb/in.^{2})	565 MPa (82,000 lb/in.^{2})	565 MPa (82,000 lb/in.^{2})
Elongation	25%	27%	27%	27%

duced penetration into the base metal. It is important to keep the arc on the leading edge of the weld pool to assure proper tie-in to the base material.

Special Cases

Problems encountered can often be fixed. For example, a small weld made on a heavy steel part cracked immediately after welding. The cause was attributed to the very high restraint being placed on the small weld bead. Also, a high-strength stainless steel alloy was used as the filler metal, which further stressed the weld joint. The solution was to use a lower strength carbon steel filler metal and a larger, more convex weld bead.

In another case, a crack occurred when welding on a small threaded part. A chemical analysis performed on the part indicated it was made from free-machining steel. This particular alloy used a high sulfur content to aid the machinability. Some free-machine alloys also use additions of lead or phosphorous. High sulfur, phosphorous, or lead additions can only lead to poor quality welds. The solution for this application is simply to not weld free-machining steels. The machine shop should pick another alloy.

Summary

Selecting the proper process is the first task of ensuring quality welds. Gas metal arc welding can be used very effectively to achieve the desired results. Picking the proper filler metal is also critical. An AWS ER70S-7 welding wire is a good choice for welding mild steel.

For GMAW, selecting and maintaining the proper welding voltage, wire feed speed, and electrode extension are very important to achieving quality welds. The resulting welds should be checked and verified to be sure they meet the requirements. As a minimum, all welds should be visually inspected for undercut and smooth transition to base metal. When satisfactory welds are produced, record the machine settings for future reference.◆