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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 ER70S-2 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 ER70S-2 produces 565 MPa (82 ksi) tensile strength with 31% elongation. The GTA welds also have low inclinations 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 ER70S-2 GTAW rods for sale.

Some believe they should weld with an AWS ER80S-D2 moly-containing rod. However, the ER80S-D2 alloy rod has a 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 ER70S-2 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.

<table>
<thead>
<tr>
<th>Element</th>
<th>4130 No Filler</th>
<th>AWS 80S-D2</th>
<th>AWS 70S-2</th>
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<tbody>
<tr>
<td>Carbon</td>
<td>0.33</td>
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<td>Manganese</td>
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<tr>
<td>Structure</td>
<td>Martensite</td>
<td>Some Martensite</td>
<td>Little Martensite</td>
</tr>
<tr>
<td>Critical Diameter</td>
<td>60 mm</td>
<td>84 mm</td>
<td>53 mm</td>
</tr>
<tr>
<td>Crack Potential</td>
<td>High</td>
<td>High to Moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Fig. 1 — Crafts and Lamont define a way to estimate a measure of steel hardenability using the chemical composition. An AWS ER70S-2 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.

Many fabricators successfully use ER70-S6 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 assembled 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
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 ER70-6S or ER70-S6 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 barbecue 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 hightemperature 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.

References


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