NIMBUS DESIGN

Specialist Framebuilders for Road, Track & Time-Trial
Columbus Tubing

Welding Notes and Application to Cycle Frame Building

(Jim Cook MCEI)

WELDING NOTES and Application to CYCLE FRAME BUILDING.

ALL TUBE SETS WHEN DISPATCHED FROM COLUMBUS HAVE A PROTECTIVE COATING. IT IS ESSENTIAL THAT CLEANING INTERNALLY AND EXTERNALLY IS CARRIED OUT PRIOR TO ANY JOINING PROCESS TO ELIMINATE CONTAMINATION IN THE WELD AREA IRRESPECTIVE OF THE METHOD OF JOINING TO BE EMPLOYED.

Tube joints and mitres for either lugged or lugless construction must be accurate to within 0.2mm of the material thickness. Gaps greater than this will affect the joint strength and fatigue life of the finished frame. If the builder intends to TIG weld the frame, Distortion of the welded joint will be proportional to any gap in the joint due to the gap closing as the weld progresses. Expansion and contraction takes in three planes, along, across and through the weld.
Joint areas with the exception of Titanium should be pre-heated to approximately 150 degrees Centigrade. Excessive temperatures above the Ac3 point (upper critical temperature) during joining operations and the length of time at Ac3 are other factors which will affect final joint efficiency and fatigue life. The Ac3 point being calculated from the C.E. (carbon equivalent) value on the Iron carbon equilibrium diagram. Dependent on composition of the material the AC3 temperature can be in the region of 800^{o}C to 900^{o}C. The chemistry of Nivacrom steel is designed to resist temperatures in excess of this by the addition of Vanadium and Niobium which precipitate into the metal matrix to prevent grain enlargement and formation of chromium carbides.

The CE is calculated from the following formula.

$$(CE) = \%C + \frac{\%Mn}{6} + \frac{(\%Ni + \%Cu)}{15} + \frac{(\%Cr + \%Mo + \%V)}{5}$$

A CE of 0.15 % or less presents very little problem, as the CE increases to say 0.41% the risk of brittle fracture (cold cracking) can occur. The history of the weld in terms of composition, cooling rate, Hydrogen absorption and stress on the joint are factors that will contribute to crack sensitivity. Hardness figures above 350 VPN in the HAZ (heat affected zone) are prone to cracking as the weld cools to below about 300^{o}C. Rapid cooling of the joint area can result in a brittle formation in the HAZ. Air hardening types are also extremely sensitive to this problem. Controlled pre-heat and protection from chilling of the finished joint must form part of the standard procedure of the frame builder.

Welding engineers recognize that failure in the HAZ is due to lack of control during the production process, materials that have a high C.E must have a proven weld procedure & quality control method in the production phase . Hardness and reduced elongation below 1O% in the HAZ are not desirable features for extended fatigue life. .

When materials exhibit too many problems either in production or in service, the simple solution is to change the material to eliminate the major source of the problem. The objective of a weld or joining procedure is to produce in the finished article the same tensile, elongation and hardness figures that are compatible to the parent material in its pre welded condition.

Columbus research department is well aware of the problems in the production of cycles frames and the arduous conditions in modern cycle racing. By virtue of this, the design of TUBE sets and the chemistry of the basic alloy steel reflects that awareness. As the fabrication of frames is beyond the control of the tube manufacturer the composition of the alloy steel must be designed to resist the prolonged high temperatures that may be used in the various joining methods i.e. TIG, Fillet brazed, Lugged etc. *NIVACROM* steel is designed to meet this criteria.

Increased hardness and lower elongation figures to produce an apparently stiffer frame are in the writers opinion a design route that fails to take into account the stresses imposed on a light weight racing cycle frame. Consider the number of reversals of load the bottom bracket/seat tube/down tube cluster is subject to in the course of a normal season for an average rider. Say 7000 miles at average speed of 18 mph = 388 hours multiply this by the cadence rate, allow for freewheeling and hill climbing, the figure is in excess of 1 million. Other factors such as riders weight, strength, type of terrain present a rough picture of just how much fatigue stress the simple cycle frame can absorb in normal service conditions. The stress concentration areas are well known, as evidenced by the location of complete, or partial fracture of the tube on a frame that has undergone high stress loading or, excessive heating and uncontrolled cooling during manufacture, resulting in premature failure in the HAZ. Given a combination of heavy rider and higher stress loading the obvious answer is use larger tube diameters.

Lugged Frames

Brazing material in common use being 9%Nickel bronze to BS 1453 C5 Melting rage 890-920 ^{o}C with a Borax based flux. A soft neutral flame (Oxy-Acet.) VICTOR 00TE Tip being large enough for thin wall tubing. Direct heating of the tube should be avoided. The flame should be applied mainly to the lugs allowing the brazing material to effect the heat transfer to the tube. Excessive time or temperature coupled with a reducing flame will increase the CARBON & HYDROGEN levels in the joint . Both these will lead to premature failure. Overheating of the tube and braze material will result also in a zinc loss porosity and the ingress of copper in to the grain structure of the tube and lug. An alternative to C5 Nickel Bronze is a Silver Quaternary alloy in the 680-720 ^{o}C temperature range, type 1665.

Fillet Brazed

Filler material is typically Nickel.Bronze type C5 or Silver Alloy type 1665 using a welding nozzle size of VICTOR 000 / 00TE Tip. Flame setting for Nickel bronze, very slightly oxidizing to eliminate the possibility of porosity in the braze deposit. Silver alloys should be applied with a slightly reducing flame by virtue of the rapid oxidation of silver. Actual joint temperature in fillet brazing is lower due to the process being in the solidous range of the filler material. The method with both materials should be two stages;

- To obtain a complete tinning of the joint area and penetration into the internal faces.
- Filling to produce fillet size and profile with the flame setting for the filler type.
- A radius of 10—15 mm produces a fiilet of the correct strength and aesthetic shape
- Thickness through the weld throat should be 4 times material to produce 100% joint efficiency

With both techniques accurate flame setting and tip size are the key factors

Note: Fluoride base fluxes are extremely corrosive

TIG WELDING ALLOY STEEL TUBING

Direct Current DC TIG (Tungsten Inert Gas)

The heat to fuse the material to be welded is generated by forming an electric arc between a tungsten electrode which is connected to the negative pole of a DC power source and the work piece. The resulting weld pool is protected from the atmosphere by an inert gas (Argon) this is supplied to the weld area by a concentric ceramic nozzle surrounding the non consumable electrode. Filler rod is added to the weld pool to complete the weld. Welds can be made with out filler wire these are termed *Autogenous.*

The welding technique for TIG is leftward as oxy/acet welding; welders with experience very quickly adapt. Tig welding should be viewed as an economic process rather than technically superior on alloy steel tubes. The weld should be a concave profile without undercutting with a throat thickness at least 1.5 X the tube wall thickness. This refers to a fillet weld. The internal of the tubes must be purged with pure argon at ambient pressure to eliminate the formation of oxides. Complete penetration is required to give the weld 100% efficiency and eliminate lack of fusion defects.

The ARC temperature in argon gas is approx. 3900^{o}C with the heat input localised to the weld area. As a result distortion will increase due in part to the low welding speeds and high temperatures. It is recommended that close space tack welds i.e a minimum of 4 are applied to the main tubes prior to completing the circumferential weld of the tube. This is a well-tested technique I used on thin gauge stainless steel in the fabrication industry over the past thirty years with the TIG process.

The need to purge the tube internal is also based on considerable experience in the Nuclear industry on materials similar in thickness to cycle tubing. Cracks can initiate from an oxidized internal due to penetration of oxides into grain boundaries of the parent material. It may appear that a comparison with Nuclear standards is a little over the top, but in the writers opinion welding thin wall alloy steel with TIG requires the same amount of care, anything less is inviting problems that will not improve your reputation as a builder or business profits.

NOTE: Filler material must be compatible with tube composition.

Plasma Arc

This process is a further development of TIG; the arc is generated within the torch head between the tungsten electrode and copper tip. The high temperature plasma column generated refers to a gas (pure argon) that has been ionized sufficiently to conduct an electrical current. The main advantage over Tig welding is that the narrow column is less critical to stand off distance, making this the ideal process for thin wall tubing in restricted access areas. This advantage is shown to the full particularly when welding titanium. Both processes Tig and Plasma are enhanced when used in a pulsed current mode. For technical reasons referred to above Plasma welding should be the first choice for automatic welding on dedicated welding machines.

Equipment

Choice is the key to quality welding and therefore economic success. The types of TIG units available can be confusing to the first time user, let's start with the size of unit or capacity which is expressed in amps at say 60% duty cycle i.e. 6 mins use in a 10 minute period.

- Machines for steel tubing should be in the region of 130-190 amps DC(direct current)
- Machines for Aluminium alloys 250 amps AC (alternating current).

The HOBBY type welders for TIG are not recommended for serious work, as the degree of arc control is poor. The producers in the Pacific Rim area use almost exclusively Inverter type welding units these are available as DC or AC/DC output with pulsed current mode. Output frequency is typically 32K Hz (32,000 cycles sec) with a pulse rate of 500Hz. This produces a stiff narrow arc column, essential for welding thin wall tubing. Certain models of INVERTER require only a 230/110-volt single phase supply, lower power demand being one of the advantages of this new technology.

The TIG welding of Aluminium cycle tubing is far easier an Inverter power unit, the resultant waveform that is generated by this technology i.e. AC. Negative - positive wave form biased to a longer negative period with square cut off at the set current, the result is a highly stable and narrow arc. This allied with pulsed current produces the neat weld pattern as seen on the majority of alloy frames from the Far East. Frame builders who wish to move into Aluminium production are advised to investigate equipment performance before purchase. Beware of the cheap machine that will do everything, It may do, but it does everything badly. Inverters are not cheap but scrap frames are expensive.

The older type units of the mid 70's design i.e. diode/thyristor rectifier systems are intended for heavy industrial materials of 6mm plus thickness, the arc control and stability at low amperages makes them unsuitable for thin alloy tubing. To obtain the performance now available from Inverter equipment specialized equipment was available but the cost was prohibitive. By direct comparison Inverter technology has surpassed the performance of the older specialized units at a reasonable cost. Plasma welding units have also followed the Inverter route with the same increases in performance at a lower capital cost.

Inverters 1995 Designs.

AC input--- Rectify to DC --Chop to AC (TR--TR) Rect--DC + Pulse + AC wave form bias
50 Hz 32k Hz 32K Hz

Thyristors 1975 Designs.

AC input ---(TR--TR) Rectify to DC
50Hz 50 Hz

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TIG AND PLASMA

Application

The economic advantages of TIG/Plasma welding are self evident by the volume of frames welded by this process being produced in the Pacific rim. We must however, bring to the notice, a few important considerations. High strength thin wall tubing welded with either TIG or PA process requires a high degree of skill. The tube preparation requires extremely accurate joints and almost surgical cleanliness of the weld area. The reason being that, argon gas only prevents the formation of oxides; it does not remove them. Do not use argon/hydrogen mixes in an attempt to speed up the welding. Hydrogen, being soluble in the molten pool will result in brittle fracture. The internal of the weld joint must be protected by argon purging, with sufficient venting by drilling the tube at the intersections to prevent an internal pressure rise.
Touching down with the exposed TIG tungsten electrode into the weld pool during welding or at the start will cause tungsten inclusions. This is another well documented cause of cracking in TIG welds. In plasma welding the electrode is inside the torch head therefore this problem is eliminated.

Typical welding conditions TIG(Steel Tube)1.0 mm wall thickness.

- ***Equipment***

  D/C output current Inverter type eg ***THERMAL ARC 190 GTS or 130 GTS***

- ***Electrode***

  1.6 mm 2% Thoriated. Tungsten

- ***Amperage***

  25A - 50A pulsed 0.7 sec on 0.7 sec off (mark -space)

- ***Gas***

  Pure Argon 99.998% pure flow rate 10 Cu/ Ft hr.

- ***Filler wire***

  1.6 mm compatible with tube composition. Filler wire for Cyclex or 25 CR Mo 4 = AMS 6457.

- ***Technique***

Torch angle 60^0 Filler wire 30^0 Purge internal of tubing , spot tack weld in 4 places i.e. 12 , 3 , 6, 9,(clock face) Wire brush tack welds, complete weld in sequence 6-3-12 and 6-9-12. Filler wire addition to be minimum of 50% of weld pool technique.

NOTE: Do not weld without filler wire by fusing the tubes together, this will result in an under size weld and with some materials can cause porosity due to a lack of deoxidisers in the in the parent material.

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TITANIUM

The welding of titanium by either the Tig or PA process is probably the easiest and most predictable with regard to weld pool behavior and normally produces a very smooth weld profile (that is the end of the good news!).

Titanium is noted for its very high fatigue life which deteriorates rapidly with the absorption of oxygen and nitrogen (atmospheric attack during welding). Weld color is a guide to the approximate condition of the weld performance as follows.

Silver:
No contamination, the weld will be equal to the parent material regarding strength and fatigue life.
Straw Color:
This indicates slight absorption of O_2 /$N_{2\ with}$ a resultant loss in ductility (caution required for extreme service).
Blue:
This indicates a high absorption of O2/N2, with a massive loss of strength. Catastrophic failure can be expected in a stress condition (scrap).

The weld discoloration caused by the absorption of oxygen and nitrogen can be polished off. This only removes the surface evidence, the problem of oxides between grain boundaries within the structure of the material remains. This can be proved by micro examination of the failed weld or adjacent area.

High Purity argon 99.998% must be used for all welding and purging of titanium. The welding of titanium is normally carried out in a chamber filled with HP Argon, anything less is a compromise on weld quality and therefore, the service life expected from the component.

These are guidance notes only and therefore we recommend they should culminate in a series of test welds, which can be used to establish a qualified procedure, which the builder can use as evidence in his quality control procedures.

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