Geoff B Associates

2, Nightingale Drive
Whitby

YO22 4QP
+ 44 (0)7525422055
www.geoffbassociates.com

Technical Paper – Welding of large section fork-arm flats

Materials – fork-arm flats & attachments

1. Boron Steel – typically; 0.32%C, 1.250%Mn, 0.5%Cr, 0.003%B

2. RO651 – typically; 0.33%C, 1.00%Mn, 1.00%Cr, 0.20%Mo

3. HRO774 – typically; 0.33%C, 0.60%Mn, 1.25%Cr, 3.25%Ni, 0.55%Mo

4. Structural steel grades or their equivalents, typically; S355J2, S355K2, S355N, are used for attachments.

5. Welding consumables are to be consistent with the chosen material grades.

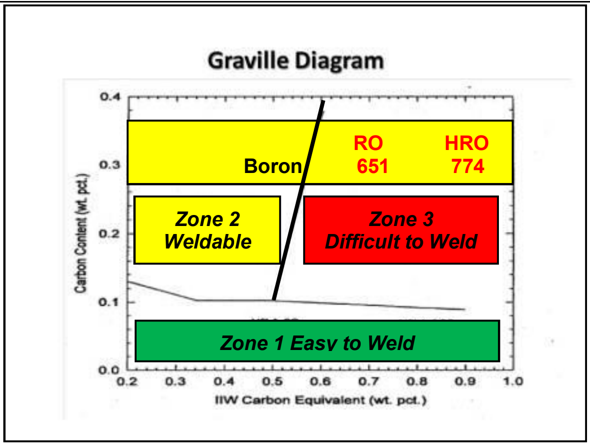
Carbon Content, Carbon Equivalent and Weldability

The Graville diagram describes the relationship between carbon content and carbon equivalent.

The diagram is divided into three zones and it is clearly seen that:

1. Boron steels are weldable.

2. RO651 and HRO774 are increasingly more difficult to weld.



HAZ Micro-structure and Cooling Rate

The maximum desired hardness in the HAZ (heat affected zone) is 420Hv, which means that any martensite which is formed must be tempered.

The HAZ is made up of four distinct regions, as we move from the fusion line to the unchanged parent metal.

1. Grain coarsened region – most susceptible to martensite formation – associated with the poorest mechanical and toughness properties.
   a. If, hydrogen induced cracking is to be encountered it will be initiated in this region.
   b. This region is more extensive in RO651 and HRO774, due to the absence of grain refining elements in the steel chemistry.

The final micro-structure is dependent on the cooling rate;

Steel	> 500^{0}C per min	> 200^{0}C per min	50-200^{0}C per min	< 50^{0}C per min	< 1^{0}C per min
Boron	Increasing Martensite	Bainite	Increasing Bainite	Ferrite + Pearlite	Ferrite + Pearlite
RO651	Increasing Martensite	Bainite	Increasing Bainite	Ferrite + Pearlite	Ferrite + Pearlite
HRO774	Martensite	Martensite	Martensite + Bainite	Bainite	Ferrite

2. Grain refined region – best mechanical and toughness properties.
   a. The presence of titanium in boron steels extends the grain refined region and the grain coarsened region is much reduced.

3. Inter-critical region – mixed microstructures; ferrite, pearlite, bainite, martensite; depending on cooling rate; therefore, variable mechanical and toughness properties.

4. Secondary hardening region – associated with precipitation of carbides; characterised by increasing strength and decreasing toughness.
   a. RO651 and HRO774 with higher chromium and molybdenum contents are more susceptible than boron steel to the effects of secondary hardening.

Heat Input

The manufacture of large section fork-arms, joint design and welder access necessitates that the initial root pass is an ultra high heat input weld, i.e ~7kJ/mm; which can be reduced in subsequent passes.

The ultra high heat input means that the initial cooling rate will be very high; to mitigate any ‘quench effects’ the cooling rate requires to be controlled through; pre / post heating, control of interpass temperature.

Pre-heat Temperatures

1. Boron steels up to 150^{0}C – minimum 100^{0}C – using localised heating

2. RO651up to 250^{0}C – minimum 100^{0}C – using localised heating

3. HRO774 up to 300^{0}C – minimum 100^{0}C – furnace heating is recommended.

Post-heat Temperatures

1. Boron steels ~ 200^{0}C – maximum 225^{0}C is sufficient to stress relieve and auto temper any martensite which may have formed. Localised heating is sufficient.

2. RO651 ~ 250^{0}C – maximum 300^{0}C is sufficient to stress relieve and soften / temper any martensite. Localised heating is sufficient; however, an extended time is required as this material does not auto temper.
    a. Temper embrittlement may occur if temperatures in excess of the maximum are used.

3. HRO774 – an extremely slow cooling rate is desirable. It is recommended to vermiculite and / or ceramic blanket cool, prior to a furnace post weld treatment ~ 520-570^{0}C.

Summary and Conclusions

1. Boron steels are the most easily weldable of the three choice materials

2. RO651 can be welded using similar procedures to boron steels, with minor modifications; pre-heat and post-heat temperatures, post heating time.

3. HRO774 requires scrupulous attention, particularly; pre-heat temperature and control, post weld cooling and post weld heat treatment.

Responsibility

Welding and weld co-ordination is the sole responsibility of the manufacturer, who shall appoint at least one RWC (Responsible Welding Co-ordinator).

Prepared by
Geoffrey E Bolton Prof MICME, MIMMM, C Eng.
Geoff B Associates