Welding Job Knowledge

Welding of nickel alloys - Part 2

In Part 1 the importance of cleanliness, particularly the removal of all sulphur containing compounds, was mentioned. With respect to defect free welding of nickel and its alloys this cannot be over-emphasised.

As well as sulphur, however, there are several other substances that can lead to embrittlement of the nickel alloys when they are exposed to high temperatures. Amongst these are lead, phosphorus, boron and bismuth.

These may be present in oils, grease, cutting fluids, paints, marker pen inks, temperature indicating crayons, etc; it may not be possible to avoid using these during fabrication so it is essential that these are removed if the component is to be welded, heat treated or is to enter high temperature service.

Fuel gases frequently contain sulphur and it may be necessary to use radiant gas heaters or electrical elements for local heating or in heat treatment furnaces.

Nickel alloys can be welded using all the conventional arc welding and power beam processes, the commonest processes being TIG or MIG with pure argon, argon/hydrogen or argon/helium mixtures as shield gases and MMA where basic flux coatings provide the best properties.

However, if argon/helium mixes are used it is only when there is more than 40% helium that any significant benefits with respect to penetration and improved fusion will be noticed. Submerged arc welding is restricted to welding solid solution alloys using basic fluxes. Matching welding consumables are available for most of the nickel alloys. See Job Knowledge 22 for recommendations for a range of alloys.

Slag from MMA welding and particularly submerged arc welding can be difficult to remove from the nickel alloys and often needs to be ground between runs to remove it completely. It is also often necessary to grind the surface of each run when welding with the gas shielded processes to remove oxide scabbing, wire brushing simply polishing these oxides.

Failure to remove slag or oxide scabs will result not only in weld metal inclusions but also reduce corrosion resistance if left on exposed surfaces. Total welding times can therefore be substantially longer than the equivalent joint in stainless or carbon steel and welders need to be fully acquainted with these differences when converting from welding steels to nickel alloys.

Comments regarding the recommended weld preparations were included in Part 1. Although the weld preparations are similar to those used for steel it is worth considering the use of double V or U type preparations at thicknesses less than would be considered with steels. The additional cost of the preparation is offset by savings in consumable costs (nickel being an expensive metal) and welding time.
The majority of nickel alloys are best welded in the annealed or solution treated condition, particularly if the alloys have been cold worked. As mentioned in Part 1, preheat is not required except to remove condensation or if the ambient temperature is below about 5°C when a moderate preheat of 40-50°C is recommended.

Interpass temperature should not be allowed to rise above 250°C although some alloy suppliers recommend an interpass as low as 100°C for certain alloys such as Alloy C276.
Remember the potential hot crack problems if thermal crayons are used to measure this temperature! For most alloys heat input should be controlled to moderate levels (say 2kJ/mm maximum) to limit grain growth and HAZ size although for some Alloys 718, C22, and C276 for example, a maximum heat input of 1kJ/mm is recommended.

Conversely if too fast a travel speed is used in an attempt to maintain a low heat input this can result in a narrow weld bead sensitive to centre line cracking. Adequate testing during welding procedure development should be used to optimise the range of acceptable welding parameters.
The solid solution alloys such as Alloy 200 or 625 do not require post weld heat treatment to maintain corrosion resistance but may be subject to PWHT either to reduce the risk of stress corrosion cracking if the alloy is to be used in caustic soda service or in contact with fluoro-silicates or to provide dimensional stability.

A typical stress relief treatment would be 700°C for ½ an hour for Alloy 200; 790°C for four hours for the higher chromium content alloys such as Alloy 600 or 625. The nickel-molybdenum alloys are identified with the prefix B *eg* B1, B2, *etc*. and are used in reducing environments, such as hydrogen chloride gas and sulphuric, acetic and phosphoric acids. Alloy B2 is the most frequently encountered alloy and matching filler metals are available. Unlike Alloy B1, Alloy B2 does not form grain boundary carbide precipitates in the weld heat affected zone, so it may be used in most applications in the as-welded condition. Alloy 400, a 70Ni-30Cu alloy, has good corrosion resistance when exposed to hydrofluoric acid, strong alkaline solutions and sea water. A matching filler metal, Alloy 190, is available but this can become anodic in salt solutions, leading to galvanic corrosion and it is recommended that one of the Ni-Cr alloy fillers such as Alloy 600 or 625 is used in this environment.

The age hardened alloy K-500 does not have a matching filler metal and is generally welded using the Alloy 190 filler, the reduction in strength being taken into account during the design phase.
Precipitation hardened alloys are best welded in the solution treated condition; welding these alloys in the age hardened condition is likely to result in HAZ cracking.
The ageing process in the alloys is sufficiently sluggish that the components can be welded in the solution treated condition and then aged at around 750°C without the mechanical properties being degraded.
A solution treatment of the welded item followed by ageing will provide the highest tensile strength.
The sensitivity of the age hardened alloy to cracking causes problems when attempts are made to repair items, particularly when these have been in high temperature service and additional precipitation on the grain boundaries has occurred.

Little can be done to overcome this problem apart from a full solution heat treatment but this is often not possible with a fully fabricated component. If repair is to be attempted, small weld beads and controlled low heat input welds are recommended.
If the design permits, a low strength filler metal, *eg* Alloy 200 or 600, may be used to reduce the risk.
Buttering the faces of the repair weld preparation, sometimes combined with a peening operation, has been successful.

Many of the nickel alloy filler metals have been used for making dissimilar metal joints with excellent results; dilution when welding joints between ferritic, stainless and duplex steels being less important than when using a type 309 stainless steel filler.

Nickel also has a coefficient of thermal expansion between that of ferritic and austenitic steels and therefore suffers less from thermal fatigue when high temperature plant is thermally cycled. Alloy 625 has been a popular choice, the weld tensile strength matching or exceeding that of the parent metal. There are limitations to this approach, and caution needs to be exercised when selecting a suitable filler. For example, Alloy 625 has been extensively used for welding dissimilar joints in austenitic and duplex steels.
Use of this filler metal has resulted in the formation of niobium rich precipitates adjacent to the fusion line and has been discontinued. Alloy 59 or C22 filler metals has replaced Alloy 625 as the filler of choice.

The moral of this is, if there is any uncertainty, ask an expert!