Welding Job Knowledge

Welding of nickel alloys - Part 1

Nickel is a relatively simple metal. It is face centred cubic and undergoes no phase changes as it cools from melting point to room temperature; similar to a stainless steel. Nickel and its alloys cannot therefore be hardened by quenching so cooling rates are less important than with, say, carbon steel and preheating if the ambient temperature is above 5°C is rarely required. Nickel and its alloys are used in a very wide range of applications - from high temperature oxidation and creep resistance service to aggressive corrosive environments and very low temperature cryogenic applications. Nickel may be used in a commercially pure form but is more often combined with other elements to produce two families of alloys - solid solution strengthened alloys and precipitation hardened alloys. Typical compositions of some of the more common alloys are given in the *Table*.

Table. Typical composition and properties of some of the more common alloys

Alloy designation	Alloy type	Typical chemical composition %								Mechanical properties		
		Ni	Cr	Mo	Fe	Nb	Al	Ti	Others	0.2% proof, MPa	UTS, MPa	El, %
Alloy 200	CP	99.2	-	-	0.2	-	-	-	Mn 0.3	148	452	45
Monel® 400	SS	68	-	-	1.75	-	-	-	Cu 33	235	562	38
Monel® K500	PH	65	-	-	1.25	-	2.95	0.55	Cu 32	795	1100	18
Alloy 600	SS	75	15.5	-	8.5	-	-	-	-	305	670	40
Alloy 617	SS	46	22	9	0.75	-	1.25	0.45	Co 12.5 B 0.004	345	725	60
Alloy 625	SS	64	22	8	2.75	3.65	0.25	0.25	-	472	920	45
Alloy 718	PH	52	19	3	Rem	5.2	0.5	0.95	-	1100	1420	18
Alloy 800	SS	32	22	-	42	-	0.45	0.45	-	290	605	42
Alloy 825	SS	42	21.5	3	28	-	0.1	0.9	Cu 2.25	330	715	39
Alloy C276	SS	55	15.5	16	5.5	-	-	-	W 3.75	345	795	60
Nimonic® PE16	PH	44	16.7	3.3	29	-	1.2	1.2	B 0.004 Zr 0.03	450	825	28

All the conventional welding processes can be used to weld nickel and its alloys and matching welding consumables are available. As mentioned above, nickel and its alloys are similar in many respects to the austenitic stainless steels; welding procedures are likewise also similar. Nickel, however, has a coefficient of thermal expansion less than that of stainless steel so distortion and distortion control measures are similar to those of carbon steel.

The most serious cracking problem with nickel alloys is hot cracking in either the weld metal or close to the fusion line in the HAZ with the latter being the more frequent. The main source of this problem is sulphur but phosphorus, lead, bismuth and boron also contribute. Both weld metal and HAZ cracking are generally the result of contamination by grease, oil, dirt, etc left behind following inadequate cleaning; excess sulphur in the parent or weld filler metals causing a problem is a rare event. Machining or vigorous stainless steel wire brushing followed by thorough degreasing with a suitable solvent is necessary prior to welding, with the welding taking place within about eight hours to reduce the risk of contamination. Any heat treatment must be carried out using sulphur-free fuel or by using electric furnaces. Components that have been in service and require weld repair may need to be ground or machined prior to degreasing to remove any contaminants that have become embedded in the surface in or adjacent to the weld repair area. Remember that if mechanical wire brushing is carried out AFTER the degreasing operation or during welding the compressed air from air powered tools contains both moisture and oil and the cleaned surfaces may be therefore be re-contaminated.

Porosity can be a problem with the nickel alloys, the main culprit being nitrogen. As little as 0.025% nitrogen will form pores in the solidifying weld metal. Quite light draughts are capable of disrupting the gas shield and atmospheric contamination will occur resulting in porosity. Care must be taken to ensure that the weld area is sufficiently protected and this is particularly relevant in site welding applications. With the gas shielded processes, gas purity and the efficiency of the gas shield must be as good as possible. Gas hoses should be checked for damage and leaks at regular intervals and, with the TIG process, as large a ceramic shroud as possible should be used together with a gas lens. It goes without saying that gas purging of the root is essential when depositing a TIG root pass.

A small amount of hydrogen (up to 10%) added to the argon shield gas has been found to reduce the problem. Start and finish porosity is a problem when MMA welding. The weld start should be carried out by welding back over the arc strike position, remelting any porosity that has formed due to the poor gas shielding at the start of the weld. Care also needs to be taken at the weld end, with the arc length reduced and travel speed increased slightly to reduce weld pool size.

Oxygen is also a cause of porosity in certain circumstances when it combines with carbon in the weld pool to form carbon monoxide. Consumable manufacturers generally overcome this problem by ensuring that sufficient deoxidants (primarily manganese, aluminium and titanium) are present in the filler metal.

One feature of nickel alloys that is often encountered is the formation on the surface of the weld pool of a viscous and adherent scum. This can be difficult to remove and can result in inclusions and lack of inter-run fusion if not removed prior to depositing the next pass. Wire brushing is frequently not sufficient to remove this layer and it then becomes necessary to grind the weld surface.

The weld pool, in addition to this surface film, is also sluggish and does not flow freely as with a carbon or stainless steel. This may result in a lumpy and very convex weld bead and a poor toe blend unless the welder manipulates the weld pool to avoid such defects. Although stringer beads may be used, a slight weave to assist the weld metal to wet the side walls of the preparation is beneficial. In addition, weld preparations must be sufficiently wide to enable the welder to control and direct the weld pool; an included angle of 70 to 80° is recommended for V butt welds.

A U preparation included angle of 30 to 40° is acceptable and, though more expensive to machine than a V preparation, may be cheaper overall as the amount of filler wire required can be reduced, depending on material thickness. Addition of hydrogen to the shield gas (up to 10%H in argon) in TIG welding also has been found to be beneficial in reducing the weld pool surface tension.

A further characteristic of nickel alloys is that the amount of penetration is less than with a carbon or stainless steel. Increasing the welding current will not increase penetration. The implication of this is that the root face thickness in single sided full penetration welds should be less than with a stainless steel. It is recommended that the thickness of the root face should not be greater than 1.5mm in a zero gap TIG butt weld. Removable backing strips are very useful to control root bead shape. These can be made from copper, stainless steel or a nickel alloy. Carbon or low alloy steel backing strips should be avoided.

Although weldability of nickel and its alloys is generally good the composition, metallurgical structure and its heat treatment and/or service history all affect its response to welding. Wrought, fine grained components have better weldability than cast items as these often have significant amounts of segregation. Coarse grains may lead to micro-fissuring in the HAZ thus high heat input is best avoided. All the alloys are best welded in the annealed or solution treated condition and this applies particularly to the precipitation hardenable alloys such as Inconel 718.

Further precautions to be taken with the commoner welding processes and recommendations on the welding of specific alloys will be covered in Part 2.