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February 2012
Vol. 36

Technical Newsletter from
ADOR WELDING LIMITED
Formerly **Advani - Oerlikon Ltd.**

WELDING OF NICKEL AND ITS ALLOYS

INTRODUCTION:

Nickel is a versatile element and will alloy with most metals. Nickel and Nickel alloys are used for a wide variety of applications, the majority of which involve corrosion resistance and/or heat resistance. Some of these include:

- Aircraft gas turbines
- Steam turbines in power plants
- Medical applications
- Nuclear power systems
- Chemical and petrochemical industries

Heat-Resistant Applications: Nickel base alloys are used in many applications where they are subjected to harsh environments at high temperatures. Nickel-chromium alloys or alloys that contain more than about 15% Cr are used to provide both oxidation and carburization resistance at temperatures exceeding 760oC.
Corrosion Resistance: Nickel based alloys offer excellent corrosion resistance to a wide range of corrosive media. For all types of corrosion, many factors influence the rate of attack.

CLASSIFICATION OF NICKEL AND ITS ALLOYS:

Nickel and its alloys can be classified into the following groups on the basis of chemical composition. The Chemical composition of some popular Nickel based alloys is given in Table 1 and we have described welding procedures for various nickel alloys in Table 2.

Commercially Pure Nickel: Nickel content ranges from about 94% to virtually 100%. These materials are characterized by high density, and capable of offering magnetic and electronic properties. They also offer excellent corrosion resistance to reducing environments, along with reasonable thermal transfer. Some nickels of commercial importance include: Nickel 200, Nickel 201, Nickel 205, Nickel 270 and 290, Permanickel Alloy 300, Duranickel Alloy 301.

Nickel-copper alloys: These alloys possess excellent corrosion resistance in reducing environments and in sea water, where they deliver excellent service in nuclear submarines and various surface vessels. By changing the various proportions of the Ni and Cu in the alloy, a whole series of alloys with different electrical resistivities and curie points can be created. Some nickel-copper alloys of commercial importance include: Alloy 400 (66%Ni, 33%Cu), Alloy R-405, and Alloy K-500.

Nickel-chromium and Nickel-chromium-Iron series of alloys led the way to higher strength and resistance to elevated temperatures. Today they also form the basis for both commercial and military power systems.
Two of the earliest developed Ni-Cr and Ni-Cr-Fe alloys were:

- Alloy 600 (76Ni - 15Cr - 8Fe)
- Nimonic alloys (80Ni - 20Cr + Ti/Al)

Some high temperature variants include: Alloy 601, Alloy X75o, Alloy 718, Alloy X (48Ni-22Cr-18Fe-9Mo+W), Wasploy (60Ni-19Cr-4Mo-3Ti-1.3Al).
Some Corrosion-resistant variants in the Ni-Cr-Fe system include: Alloy 625, Alloy G3/G30, Alloy C-22, Alloy C-276 and Alloy 690

Iron-Nickel-Chromium Alloys: This series of alloys has also found extensive use in the high-temperature petrochemical environments, where sulphur containing feedstocks are cracked into component distillate parts. They offered resistance to chlorine ion stress corrosion cracking and polythionic acid cracking.
Some nickel-copper alloys of commercial importance include: Alloy 800, Alloy 800HT, Alloy 801, Alloy 802, Alloy 825, and Alloy 925.
The 800 alloy series offers excellent strength at elevated temperature (creep and stress rupture).

WELDING OF NICKEL AND ITS ALLOYS:

Nickel alloys can be joined reliably by all types of welding processes except Forge welding and oxyacetylene welding. The wrought nickel alloys can be welded under conditions similar to those used to weld austenitic stainless steels. Cast nickel alloys particularly those with high silicon content present difficulties in welding. The most widely used processes for welding the non-age hardenable wrought nickel alloys are gas tungsten arc welding (GTAW), gas metal arc welding (GMAW) and shielded metal arc welding (SMAW).Submerged arc welding (SAW), plasma arc welding (PAW) and electro slag welding (ESW) have limited applicability. Nickel alloys are usually welded in the solution treated condition. Precipitation-hardenable (PH) alloys should be annealed before welding if they have undergone any operations that introduce high residual stresses.

POST WELD TREATMENT:

No postweld treatment is required to maintain or restore corrosion resistance, although in some cases a full anneal will improve corrosion resistance. Heat treatment may be necessary to meet specification requirements such as stress relief of a fabricated structure to avoid age hardening or stress-corrosion cracking (SCC) of the weldment in hydrofluoric acid vapor or caustic soda. If welding induces moderate to high residual stresses, then the precipitation hardenable alloys would require a stress relief anneal after welding and before aging.

The defects and metallurgical difficulties encountered in arc welding of Nickel include:

- Porosity
- Susceptibility to high temperature embrittlement by sulfur and other contaminants
- Cracking in the weld bead caused by high heat input and excessive welding speeds
- Stress corrosion cracking in service

Porosity: Oxygen, Carbon dioxide, Nitrogen or Hydrogen can cause porosity in welds. In SMAW and SAW processes, porosity can be minimized by using electrodes that contain deoxidizing or nitride forming elements such as Aluminum and Titanium. These elements have a strong affinity for oxygen and form stable compounds with them. The presence of deoxidizers in the either type of electrode serves to reduce porosity. In addition porosity is much likely to occur in chromium bearing nickel alloys than in non-chromium bearing alloys.

In GMAW and GTAW processes, porosity can be avoided by preventing the access of air to the molten weld metal. Gas backing on the underside of the weld is sometimes used. In the GTAW process, the use of argon with upto 10% H_2 as a shielding gas helps to prevent porosity. Bubbles of hydrogen that form in the weld pool gather the diffusing hydrogen. Too much hydrogen (>15%) in the shielding gas can result in the hydrogen porosity.

Cracking: Hot shortness of welds can result from contamination by sulfur, lead, phosphorous, cadmium, zinc, tin, silver, boron, bismuth or any other low melting point elements, which form intergranular films and cause severe liquid metal embrittlement at elevated temperatures. Hot cracking of weld metal usually results from such contamination. Cracking in heat affected zone is often caused by intergranular penetration of contaminants from the base metal surface. Sulfur which is present in most cutting oils used for machining is a common cause of cracking in nickel alloys.
Weld metal cracking can also be caused by high heat input as a result of high welding current and low welding speed. Welding speeds have a large effect on the solidification pattern of the weld. High welding speeds create a tear drop molten weld pool which leads to uncompetitive grain solidification at the center of the weld. At the weld centerline, residual elements will collect and cause centerline hot cracking. Cracking may also result from undue restraint. When conditions of high restraint are present, as in circumferential welds that are self restraining, all bead surfaces should be slightly convex. Although convex beads are virtually immune to centerline splitting, concave beads are particularly susceptible to centerline cracking.

Stress Corrosion Cracking: Nickel and Nickel alloys do not experience any metallurgical changes either in the weld metal or in the HAZ that affects normal corrosion resistance. When the alloys are intended to contact substances such as concentrated caustic soda, fluorosilicates, and some mercury salts the welds may need to be stress relieved to avoid stress corrosion cracking. Nickel alloys have good resistance to alkali and chloride solutions. Stress relieving of welds in the high nickel content alloys is not usually needed because resistance to stress corrosion cracking increases with nickel content.

Effect of slag on weld metal: All slag should be removed from finished weldment, because fabricated nickel alloys are ordinarily used in high temperature service and in aqueous corrosive environments. If not it will result in crevices and accelerated corrosion. Slag inclusions between weld beads reduce the strength of the weld and also fluorides in the slag can react with moisture or elements in the environment to create highly corrosive compounds.

Table 1 Nominal Chemical composition(wt%)

Material	Ni	Cu	Fe	Cr	Mo	Al	Ti	Nb	Mn	Si	C	Other elements	Remarks
Nickel													
Nickel 200	99.6	-	-	-	-	-	-	-	0.23	0.03	0.07	-	
Nickel 201	99.7	-	-	-	-	-	-	-	0.23	0.03	0.01	-	
permanickel alloy 300	98.7	-	0.02	-	-	-	0.49	-	0.11	0.04	0.29	0.38 Mg	
Duranickel alloy 301	94.3	-	0.08	-	-	4.44	0.44	-	0.25	0.50	0.16	-	
Nickel-Copper													

Monel alloy 400	65.4	32	1	-	-	-	-	-	1	0.1	0.12	-	
Monel alloy 404	54.6	45.3	0.03	-	-	-	-	-	0.01	0.04	0.07	-	
Monel alloy R-405	65.3	31.6	1.25	-	-	0.1	-	-	1	0.17	0.15	0.04 S	
Monel alloy K-500	65	30	0.64	-	-	2.94	0.48	-	0.7	0.12	0.17	-	
Nickel-Chromium-Iron													
Inconel alloy 600	76	0.25	8	15.5	-	-	-	-	0.5	0.25	0.08	-	
Inconel alloy 601	60.5	0.5	14.1	23	-	0.35	-	-	0.5	0.25	0.05	-	Improved oxidation & Nitriding resistance
Inconel alloy 690	60	-	9	30	-	-	-	-	-	-	0.01	-	Excellent oxidation and nitricacid resistance
Inconel alloy 706	41.5	0.15	40	16	-	0.2	1.8	3	0.18	0.18	0.03	-	
Inconel alloy 718	53.5	0.15	18.5	19	3	0.5	0.9	5.1	0.18	-	0.04	-	Resistance to strainage cracking
Inconel alloy X-750	73	0.25	7	15.5	-	0.7	2.5	1	0.5	0.25	0.04	-	age hardening
Nickel-Iron-Chromium													
Incoloy alloy 800	31	0.38	46	20	-	0.38	0.38	-	0.75	0.5	0.05	-	resistance to oxidation & carburization at elevated temperatures
Incoloy alloy 800H	31	0.38	46	20	-	0.38	0.38	-	0.75	0.5	0.07	-	
Incoloy alloy 825	42	1.75	30	22.5	3	0.1	0.9	-	0.5	0.25	0.01	-	pitting resistance in aqueous corrosion & resistance to H_2SO_4
Incoloy alloy 925	43.2	1.8	28	21	3	0.35	2.1	-	0.6	0.22	0.03	-	Strengthening through age hardening
Pyromet 860	44	-	Bal	13	6	1	3	-	0.25	0.1	0.05	4.0 Co	
Refractaloy 26	38	-	Bal	18	3.2	0.2	2.6	-	0.8	1	0.03	20 Co	
Nickel-Iron													
Nilo alloy 36	36	-	61.5	-	-	-	-	-	0.5	0.09	0.03	-	Lowest thermal expansion from ambient to 230°C
Nilo alloy 42	41.6	-	57.4	-	-	-	-	-	0.5	0.06	0.03	-	
Ni-Span-C alloy 902	42.3	0.05	48.5	5.33	-	0.55	2.6	-	0.4	0.5	0.03	-	Controllable thermoelastic coefficient
Incoloy alloy 903	38	-	41.5	-	-	0.9	1.4	2.9	0.09	0.17	0.02	14 Co	High strength & low coefficient of thermal expansion for
Incoloy alloy 907	37.6	0.1	41.9	-	-	1.5	-	4.7	0.05	0.08	0.02	14 Co	
Nickel-Chromium-Molybdenum													
Hastelloy alloy X	Bal	-	19	22	9	-	-	-	-	-	0.1	-	Aerospace applictions
Hastelloy alloy G	Bal	2	19.5	22	6.5	-	-	2.1	<1	1.5	<0.05	<1 W, <2.5 Co	
Hastelloy alloy C-276	Bal	-	5.5	15.5	16	-	-	-	<0.08	<1	<0.01	2.5 Co, 4W, 0.35 V	Good seawater corrosion resistance & ecellent pitting and crevice corrosion
Hastelloy alloy C	Bal	-	<3	16	15.5	-	<0.7	-	<0.08	<1	<0.01	<2 Co	
Hastelloy alloy 617	54	-	-	22	9	1	-	-	-	-	0.07	12.5 Co	
Hastelloy alloy 625	Bal	-	2.5	21.5	9	<0.4	<0.4	3.6	-	-	0.03	-	resists high temperature,wet,pitting and crevice corrosion
MAR-M-252	Bal	-	-	19	10	1	2.6	-	<0.5	<0.5	0.15	10 Co, 0.005B	
Rene 41	Bal	-	-	19	10	1.5	3.1	-	-	-	0.09	11 Co, <0.010B	
Rene 95	Bal	-	-	14	3.5	3.5	2.5	3.5	-	-	0.15	8Co, 3.5W, 0.01B, 0.05Zr	
Astroloy	Bal	-	-	15	5.3	4.4	3.5	-	-	-	0.06	15 Co	
Udimet 500	Bal	-	<0.5	19	4	3	3	-	-	-	0.08	18Co, 0.007B	
												12 Co, 1W,	

Udimet 520	Bal	-	-	19	6	2	3	-	-	-	0.05	[illegible] 0.005B	
Udimet 600	Bal	-	<4	17	4	4.2	2.9	-	-	-	0.04	16 Co, 0.02 B	
Udimet 700	Bal	-	-	15	5	4.4	3.5	-	-	-	0.07	18.5 Co, 0.025 B	
Udimet 1753	Bal	-	9.5	16.3	1.6	1.9	3.2	-	0.1	0.05	0.24	7.2Co, 8.4W, 0.008B, 0.06Zr	
Waspaloy	Bal	<0.1	<2	19	4.3	1.5	3	-	-	-	0.08	14Co, 0.006B, 0.05Zr	proprietary alloy for jet applications

Table 2 Welding Processes and consumables for various popular alloys

Material	Welding processes	Welding consumables	Suggested AWL electrodes
Nickel			
Nickel 200	SMAW	ENi-1	NICALLOY 1
Nickel 201	GTAW	ERNi-1	
Nickel-Copper			
Monel alloy 400	SMAW	ENiCu-7	SUPPERMONEL
Monel alloy R-405	GTAW	ERNiCu-7	
Monel alloy K-500	GMAW		
Nickel-Chromium-Iron			
Inconel alloy 600	SMAW	ENiCrFe-1/ENiCrFe-3	NICALLOY Fe-3
	GTAW, GMAW	ERNiCr-3/ERNiCrFe-7	TIGFIL NiCr3 AUTOMIG NiCr3
Inconel alloy 601	SMAW	ENiCrFe-3 /ENiCrMo-3	NICALLOY Fe-3/NICALLOY Mo-3
	GTAW, GMAW	ERNiCr-3/ERNiCrMo-3	TIGFIL NiCr3/TIGFIL NiCrMo3 AUTOMIG NiCr3/AUTOMIG NiCrMo3
Inconel alloy 690	SMAW	ENiCrFe-3/ENiCrFe-7	NICALLOY Fe-3
	GTAW, GMAW	ERNiCr-3/ERNiCrFe-7	TIGFIL NiCr3 AUTOMIG NiCr3
Inconel alloy 718	GTAW	ERNiCrFe-2	
Inconel alloy X-750	GMAW		
Nickel-Iron-Chromium			
Incoloy alloy 800	SMAW	ENiCrMo-5/ENiCrMo-6	NICALLOY Mo-5/ NICALLOY Mo-6
	GTAW, GMAW	ERNiCr-3	TIGFIL NiCr3 AUTOMIG NiCr3
Incoloy alloy 800HT	SMAW	ENiCrCoMo-1	
	GTAW, GMAW	ERNiCrCoMo-1/ERNiCr-3	TIGFIL NiCr3 AUTOMIG NiCr3
Incoloy alloy 825	SMAW	ENiCrMo-3	NICALLOY Mo-3
	GTAW, GMAW	ERNiCrMo-3	TIGFIL NiCrMo3 AUTOMIG NiCrMo3
Nickel-Chromium-Molybdenum			
Hastelloy alloy G	SMAW	ENiCrMo-3	NICALLOY Mo-3
Hastelloy alloy C-276	SMAW	ENiCrMo-3 through 6	NICALLOY Mo-3/NICALLOY Mo-5/ NICALLOY Mo-6
	GTAW, GMAW	ERNiCrMo-4 through 10	TIGFIL NiCrMo4 AUTOMIG NiCrMo4
Hastelloy alloy C	SMAW	ENiCrMo-5	NICALLOY Mo-5
Hastelloy alloy 617	SMAW	ENiCrMo-1	
	GTAW, GMAW	ERNiCrMo-1	
Hastelloy alloy 625	SMAW	ENiCrMo-3 through 6	NICALLOY Mo-3/NICALLOY Mo-5/ NICALLOY Mo-6
	GTAW, GMAW	ERNiCrMo-3	TIGFIL NiCrMo3 AUTOMIG NiCrMo3

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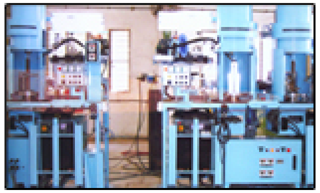

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