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Nickel and Nickel Alloys

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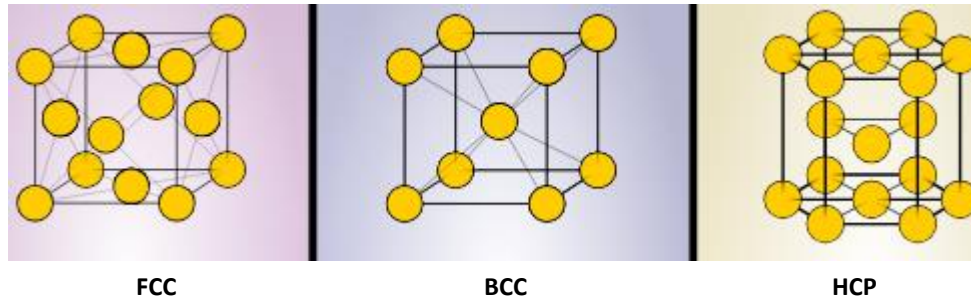
Outline



- Nickel and Nickel alloys
 - Introduction
 - Applications
 - Weldability and Issues

Nickel and Nickel Alloys

- Nickel is a chemical element (Ni) with FCC structure
- Its color is silver-white
- Malleable and ductile
- Chemically reactive (with air forms nickel oxide layer which prevents further oxidation)



Nickel and Nickel Alloys

- Interesting discovery... Sometime back in 1650s
- Miners discovered a reddish ore (niccolite – NiAs – Ni Arsenide) which was initially thought to contain copper (Kupfer)
- Upon smelling, it was extremely noxious
- Miners termed it as ‘Old Nick’, & was hindering their work in extracting copper & making it dangerous, so, called ore as ‘Kupfer Nicell’, literary meant (devil’s copper)
- Word spread throughout time
- 100 years, Nickel (Ni) was named in 1754 in Stockholm, Sweden by Axel Frederik Cronstedt, analyzing the ore to contain maximum content of Nickel.



Nickel and Nickel Alloys



- Over one hundred years later, a significant Nickel ore body was discovered in Canada. Ore contained principally sulfide compounds, also contained significant amounts of copper
- Amercian company 'Orford Copper Company' showed great interest
- Native Canadian company 'Canadian Copper Company' and 'Orford Copper Company' formed 'Inco' International Nickel Company on March 29, 1902

Nickel and Nickel Alloys



- In the same period, ‘Ambrose Monell’ discovered and patented first commercially significant nickel alloy
- It contained $\frac{2}{3}$ nickel and $\frac{1}{3}$ copper naturally, needed refining
- Became a precursor to ‘Monel’, an alloy still used today

Nickel and Nickel Alloys



- Pure Ni is extracted by roasting to NiO & then reducing with carbon.
- The Mond process is used to manufacture pure nickel, where in impure nickel reacts with carbon monoxide (CO) to produce Ni(CO)_4
- Ni(CO)_4 (Ni-tetracarbonyl) is subsequently decomposed at 200°C to yield 99.99% Ni



Nickel and Nickel Alloys



- Pure nickel is resistant to corrosion in water or air, and therefore is used as a protective coating
- Commercially pure or low alloy nickel finds its main application in chemical processing and electronics.
- Commercially pure Nickel is used for electronic lead wires, battery components, and sparking electrodes.
 - Because of its high electrical conductivity
- Can be used in heat exchangers running in high corrosive environment
 - has high thermal conductivity



Nickel and Nickel Alloys



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- NiO is a passive layer coating
 - When exposed to air or other oxidizing environments, nickel readily reacts with oxygen to form a thin, invisible nickel oxide (NiO) film on its surface
 - Unlike rust on iron, which is a bulky, flaky, and porous oxide that allows further oxidation, Nickel's passive layer, is compact, adherent, and acts as a barrier to avoid further oxidation.
 - It quickly self-heals or reforms if the passive layer is damaged or scratched
- Nickel has a low hardness and good ductility. Like gold, silver and copper, it has a relatively low work hardening rate. These attributes, combined with good weldability, make it easier to fabricate into finished items.

Nickel and Nickel Alloys

– Some properties of Nickel 200 (commercially pure ~ 99.6%)...

- | | |
|---|------------------------|
| • Tensile Strength at 20 °C | 450 MPa |
| • Density | 8.89 g/cm ³ |
| • Melting Range | 1435-1446 °C |
| • Specific Heat | 456 J/kg. °C |
| • Co-Efficient of Expansion (20-100 °C) | 13.3e-6m/m.°C |
| • Thermal Conductivity | 70 W/m.°C |
| • Electrical Resistivity | 0.096e-6 ohm.m |



Nickel and Nickel Alloys

– Role in chromium plating

- Used as an undercoat in decorative chromium plating.
- The raw product, such as a brass or zinc casting or a sheet steel pressing is first plated with a layer of nickel approximately $20\mu\text{m}$ thick.
- This gives it its corrosion resistance
- The final coat is a very thin 'flash' ($1\text{-}2\mu\text{m}$) of chromium to give it a colour and tarnish resistance that is generally regarded as more desirable in plated ware.
- Chromium alone would have unacceptable corrosion resistance because of the generally porous nature of chromium electroplate



Nickel and Nickel Alloys



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– Environmental properties

- E.g., used in food & chemical processing equipment

Environmental Properties	
	Resistance Factors 1=Poor 5=Excellent
Flammability	5
Fresh Water	5
Organic Solvents	5
Oxidation at 500C	5
Sea Water	5
Strong Acid	4
Strong Alkalis	5
UV	5
Wear	4
Weak Acid	5
Weak Alkalis	5

Nickel and Nickel Alloys

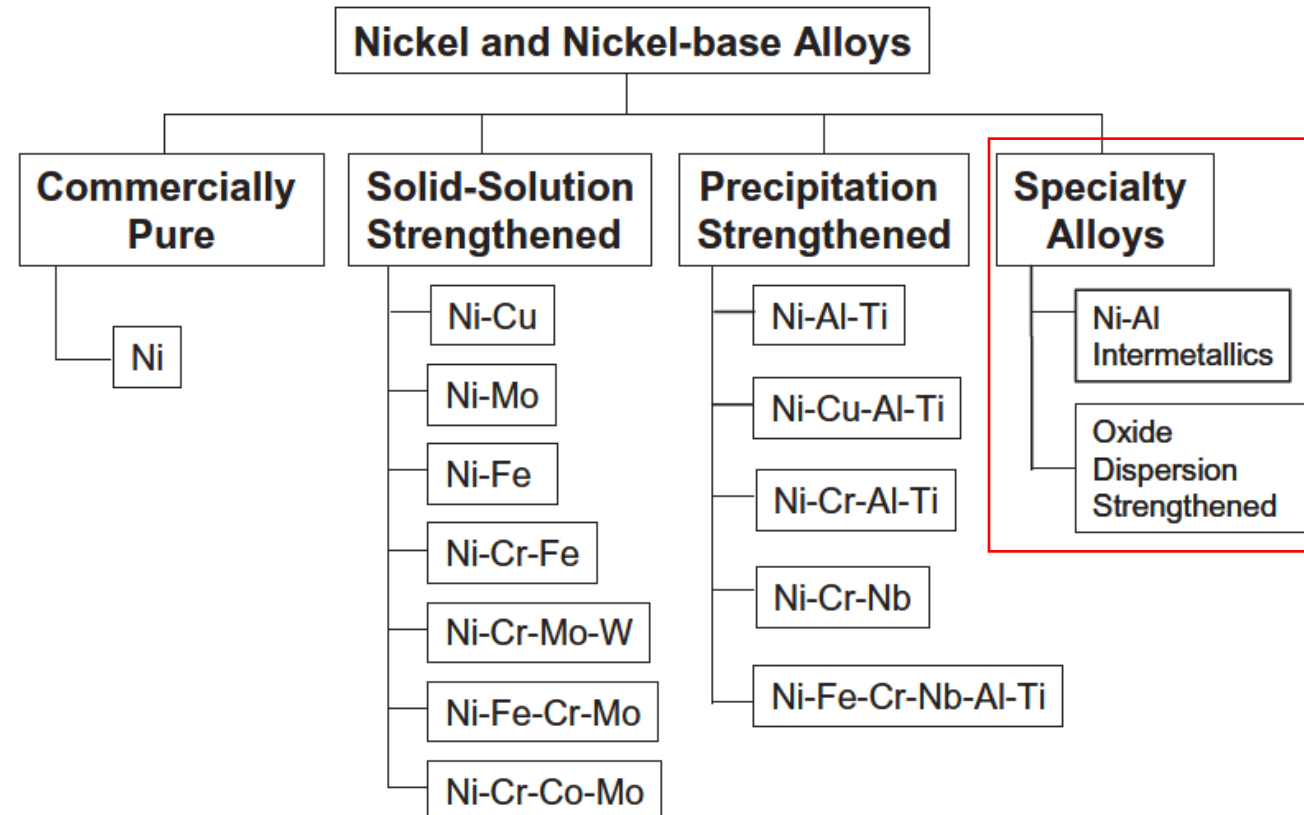


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- Most applications are in the form of its alloys
 - For instance,
 - Monel (corrosion resistant material)
 - Nichrome (an alloy used for resistance heating elements)
 - Permalloy (an alloy with high magnetic permeability at low field strength and low hysteresis loss)
 - Cupro-nickel
 - Inconel
 - Stainless steel (about 8%)
 - Nickel-silver
 - Copper-Nickel, etc.

Nickel and Nickel Alloys

– Classification of Nickel and its alloys



Nickel and Nickel Alloys



– Nickel based alloys

- Relative to steels, Ni - based alloys can be used both at extremely low cryogenic temperatures to high temperatures approaching 1200°C (2190°F)
- The Precipitation - Strengthened Ni - bases alloys contain additions of titanium, aluminum and/or **niobium that form a strengthening precipitate with nickel** after an appropriate heat treatment
- The most common of these precipitates are called gamma prime [γ' - Ni_3Al , Ni_3Ti , and $\text{Ni}_3(\text{Ti},\text{Al})$] and **gamma double prime (γ'' - Ni_3Nb)**.
- By optimizing alloying additions and heat treatment, these alloys can be strengthened to reach very high ultimate tensile strength values exceeding 200 ksi (1380 MPa) with 0.2% offset yield strengths over 150 ksi (1035 MPa).

Nickel and Nickel Alloys



– Nickel based alloys

- The range of Ni - based alloys available today is expansive and one can be chosen for nearly any type of corrosion - resisting application
- Commercially – pure nickel alloys 200 and 201 find application in the production and processing of caustic (corrode causing) chemicals such as NaOH, KOH etc.
- Ni is the key alloying element which resists stress-corrosion cracking (caused by fatigue and corrosive environment, leads to sudden failure in ductile materials)
- Alloys that contain **at least 42% nickel** are virtually **immune to chloride ion stress-corrosion cracking**
- Inconel, one of the well-known Ni alloys is not exempted.



Nickel and Nickel Alloys



– Nickel based alloys

- With this wide temperature resistance and very high strength values and excellent corrosive protection, these alloys are used in power generation, petrochemical, chemical processing, aerospace, and pollution control industries.



The Role of Nickel Alloys in Aerospace Engineering



OIL & GAS EXTRACTION



PETROCHEMICAL PROCESSING



POWER GENERATION

Nickel and Nickel Alloys



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– Nickel based alloys

- Alloy 600 applications

Jet engines

- Exhaust liners
- High temperature airframe components
- High temperature engine
- Lockwire
- Turbine seals
- Combustion-can liners
- Containment rings in gas turbines
- Diffuser assemblies
- Jet-engine igniters

Power generation

- Ash-handling systems
- Grid barriers
- Superheater tube supports

Chemical and process industries

- Bubble towers
- Condensers for processing of fatty acids
- Evaporator tubes
- Flaking trays
- Heaters
- Stills
- Tube sheets
- Catalyst grid supports in equipment for nitric acid production
- Combustor components
- Condenser tubes in sour-water
- Insulating cans in ammonia reformers
- Process heaters
- Strippers

Thermal processing

- Retorts
- Muffles
- Roller hearths
- Furnace components
- Heat-treating baskets

Petrochemical processing

- Air preheaters
- Catalyst regenerators

Waste processing

- Combustion chambers in solidwaste incinerators
- Thermal reactors in exhaust systems of gasoline engines

Power generation

- Ash-handling systems
- Grid barriers

Nickel and Nickel Alloys

- Nickel based alloys
 - Composition & some properties of some common Nickel 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



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Nickel and Nickel Alloys



– Nickel based alloys

- Production...
- Different melting methods are employed
 - Range from simple air induction melting (AIM) to complex triple melt processes (for aerospace applications e.g., gas turbine rotating parts)
- Triple melting normally involves a combination of vacuum induction melting (**VIM**), electroslag remelting (**ESR**) and vacuum arc remelting (**VAR**).
- The triple melt process is often used to produce “superalloys” that require exceptionally low impurity levels for combined high - strength and high - temperature fatigue properties.

Nickel and Nickel Alloys



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– Weldability of Nickel based alloys

- All the conventional welding processes can be used to weld nickel and its alloys
- The commonest processes being TIG or MIG with pure argon, argon/hydrogen or argon/helium mixtures as shielding gases
- A distinguishing feature of precipitation hardened alloys is that mechanical properties are developed by heat treatment (solution treatment plus ageing) to produce a fine distribution of particles in a nickel-rich matrix.

Nickel and Nickel Alloys



– Weldability of Nickel based alloys

- Solid solution alloys...
- Solid solution alloys are pure nickel (Co), Ni-Cu alloys and the simpler Fe-Ni-Cr alloys.
- These alloys are readily fusion welded, normally in the annealed condition. As the heat affected zone (HAZ) does not harden, heat treatment is not usually required after welding.
- Preheat is not required except to remove condensation or if the ambient temperature is below about 5°C. A moderate preheat of 40-50°C is recommended.

Nickel and Nickel Alloys



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- Weldability of Nickel based alloys
 - Precipitation – Hardening alloys...
 - Precipitation hardening alloys e.g., include Ni-Cu-Al-Ti, Ni-Cr-Al-Ti and Ni-Cr-Fe-Nb-Al-Ti.
 - These alloys are susceptible to post-weld heat treatment cracking.

Nickel and Nickel Alloys



– Weldability of Nickel based alloys

- Most nickel alloys can be fusion welded using gas shielded processes like TIG or MIG. Of the flux processes, MMA is frequently used but the SAW (submerged arc) process is restricted to solid solution alloys and is less widely used.
- Solid solution alloys are normally welded in the annealed condition and precipitation hardened alloys in the solution treated condition.
- Preheating is not necessary unless there is a risk of porosity from moisture condensation.
- It is recommended that material containing residual stresses be solution-treated before welding to relieve the stresses.
- Post-weld heat treatment is not usually needed to restore corrosion resistance but thermal treatment may be required for precipitation hardening or stress relieving purposes to avoid stress corrosion cracking.

Nickel and Nickel Alloys



– Weldability of Nickel based alloys

- Filler composition normally matches the parent metal.
- However, most fillers contain a small amount of titanium, aluminium and/or niobium to help minimise the risk of porosity and cracking.
- Filler metals for gas shielded processes are covered in standards BS EN 18274:2004 and in the USA by AWS A5.14.

Nickel and Nickel Alloys

- Weldability of Nickel based alloys
 - Some of filler materials used for Nickel welding

Parent alloy	Filler (BS & AWS)		Trade name	Comments
Pure nickel				
Nickel 200	Ni 2061	ERNi-1	Nickel 61	Matching filler metal normally contains 3%Ti
Nickel Copper				
Alloy 400	Ni 4060	ERNiCu-7	Monel 60	Matching filler metal contains additions of Mn, Ti and Al
Nickel Chromium				
Brightray S	Ni 6076	-	NC 80/20	Ni-Cr and Ni-Cr-Fe filler metals may be used
Nimonic 75	Ni 6076	-	NC 80/20	
Nickel-Chromium-Iron				
Alloy 800	Ni 6625	ERNiCrMo-3	Inconel 625 Thermanit 21/33	Usually welded with Ni-Cr-X alloys, but more nearly matching consumables are available which contain higher C and also Nb
Alloy 600	Ni 6082	ERNiCr-3	Inconel 82	Matching filler metal contains Nb addition
Alloy 718	Ni 7718	ERNiFeCr-2	Inconel 718	Matching filler metal is normally used but Alloy 625 is an alternative consumable , if postweld heat treatment is not applied
Nickel-Chromium-Molybdenum				
Alloy 625	Ni 6625	ERNiCrMo-3	Inconel 625	Filler metal is also used widely for cladding and dissimilar welds
Hastelloy C-22	Ni 6022	ERNiCrMo-10	Hastelloy C-22	
Nickel-Molybdenum				
Hastelloy B-2	Ni 1066	ERNiMo-7	Hastelloy B-2	Corrosion resistant alloys require matching fillers



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Nickel and Nickel Alloys



- Weldability of Nickel based alloys
 - Issues...

– Weldability of Nickel based alloys

- Nickel and its alloys are readily welded but it is essential that the surface is cleaned immediately before welding. The normal method of cleaning is to degrease the surface, remove all surface oxide by machining, grinding or scratch brushing and finally degrease.
- Common imperfections found on welding are:
 - Porosity, oxide inclusions and lack of inter-run fusion, weld metal solidification cracking, microfissuring
- Additionally, precautions should be taken against post-welding imperfections such as:
 - post-weld heat treatment cracking
 - stress corrosion cracking

Nickel and Nickel Alloys



– Weldability of Nickel based alloys

- **Porosity** can be caused by oxygen and nitrogen from air entrainment and surface oxide or by hydrogen from surface contamination. Careful cleaning of component surfaces and using a filler material containing deoxidants (aluminium and titanium) will reduce the risk.
- As little as 0.025% nitrogen will form pores in the solidifying weld metal from atmosphere (shielding gas should be properly positioned)
- When using argon in TIG and MIG welding, attention must be paid to shielding efficiency of the weld pool including the use of a gas backing system. In TIG welding, argon-hydrogen gas mixtures tend to produce cleaner welds.

Nickel and Nickel Alloys



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- Weldability of Nickel based alloys
 - **Oxide inclusions and lack of inter-run fusion...**
 - As the oxide on the surface of nickel alloys has a much higher melting temperature than the base metal, it may remain solid during welding. Oxide trapped in the weld pool will form inclusions. In multi-run welds, oxide or slag on the surface of the weld bead will not be consumed in the subsequent run and may cause lack of fusion imperfections.
 - Before welding, surface oxide, particularly if it has been formed at a high temperature, must be removed by machining or abrasive grinding; it is not sufficient to wire brush the surface as this serve only to polish the oxide.
 - During multipass welding, surface oxide and slag must be removed between runs.

Nickel and Nickel Alloys



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- Weldability of Nickel based alloys
 - **Weld metal solidification cracking**
 - Factors which control solidification cracking include alloy, welding process and welding conditions.
 - Submerged arc welding, is not applicable to welding Ni alloys.
 - More generally, this type of cracking leads to restriction of weld shape, welding speed and technique.

Nickel and Nickel Alloys



– Weldability of Nickel based alloys

- **Microfissuring**
- Nickel alloys are susceptible to formation of liquation cracks in reheated weld metal regions or parent metal HAZ.
- This type of cracking is controlled by post-weld treatments such as grain size refinement or adjusting impurity content. Some alloys are more sensitive than others.
- 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.



Nickel and Nickel Alloys



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- Weldability of Nickel based alloys
 - **Post-weld heat treatment cracking**
 - This is also known as strain-age or reheat cracking. It is likely to occur during post-weld ageing of precipitation hardening alloys but can be minimised by pre-weld heat treatment.
 - Solution annealing is commonly used but over-ageing gives the most resistant condition.
 - Alloy 718 alloy was specifically developed to be resistant to this type of cracking.

Nickel and Nickel Alloys



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- Weldability of Nickel based alloys
 - **Stress corrosion cracking**
 - Welding does not normally make most nickel alloys susceptible to weld metal or HAZ corrosion. However, when Alloy 400 will be in contact with caustic soda, or HF acid (Hydrofluoric), stress corrosion cracking is possible. For such service, thermal stress relief is applied after welding.
 - Stress corrosion can also occur in Ni-Cr alloys in high temperature water. High chromium filler metal has been developed for welds and overlays in this environment.

Thank You



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