High Purity Nickel Layers in Clad Composite Metals

A. Advantages of using high purity nickel

Certain properties of high purity nickel differ substantially from those of less pure nickel. These properties are:

Property		Degree of purity		
		Ni 99.98	Ni 99.6	Ni 99.2
Tensile Strength				
- soft temper	Rm [MPa]	300 - 350	370 - 400	370 - 450
- hard	Rm [MPa]	600 - 900	590 - 700	590 - 700
Elongation soft temper	%	> 50	25 - 40	10 - 25
Recrystallisation temperature	°C	300 - 350	690 - 720	690 - 720
Trace elements				
- C	wt. %	0,0015	0,036	0,034
- Al	wt. %	< 0,0001	0,005	0,005
- Ti	wt. %	<0,0002	< 0,02	0,045
- Si	wt. %	0,000016	0,07	0,13
- Mn	wt. %	< 0,0002	0,01	0,066
- Mg	wt. %	< 0,0002	0,01	0,01

Table 1: Properties of various grades of nickel

I. Softness as a critical factor to achieve bonding and bond strength

If nickel is an outer (one side or both sides) layer in cladding, a very soft material is advantageous. This is already the case if the core material is relatively hard in comparison to nickel, as is the case for titanium, stainless steel and steel. It is even more important if the core layer is a soft material as copper or aluminum.

Using high purity nickel increases the "Green" bond strength in the composite. The composite is then ready for the annealing process, which increases the bond strength.

Clad combinations		Outer Layer	
		soft	hard
Core	soft	• unproblematic • Examples – Al 10Si on Al (Brazing clad) – Aluminum on Pure Nickel – Nickel on Copper	• challenging • Examples – Titanium on Copper – Stainless Steel on Copper or Aluminum

Clad combinations		Outer Layer	
		soft	hard
Core	hard	• unproblematic • a low gage outer layer should be as soft as possible („Butter on Toast“) • Examples - Ni or Al on Stainless Steel	• challenging • Examples - Titanium on Stainless Steel

Table 2: Combinations of outer and core layers

II. Lacking trace elements

If Nickel is produced by conventional melting metallurgy, C, Al, Si and/or Ti are added to deoxidize the melt, Mn and Mg is added to globalize S. These elements are supposed to be slagged out, but remain partly in the melt. During the annealing process in a clad material, all these elements segregate to the clad layer and grain boundaries. Segregation to layer boundaries is particularly harmful, as brittle intermetallic phases impair bond strength and support delamination.

High purity nickel is nearly free from trace elements, so little, if any, segregation occurs.

III. Low recrystallization temperature of high purity nickel and melting point of other metals

A low recrystallization temperature is necessary if nickel is clad to a metal with a low melting point. This is even more important if the metal with a low melting temperature reacts exothermically with nickel upon melting. In addition, magnesium has a tendency to autoignite; the autoignition tempe-rature of magnesium ribbon is approximately 473 °C (746 K; 883 °F).

Combinations between standard nickel grades and aluminum or magnesium can be clad, but they they cannot be subsequently soft annealed due to the low melting points of the Al or Mg:

Metal	Melting point	Recrystallization
	°C	°C
Less pure Nickel		690 - 720
High purity Nickel		300 - 350
Magnesium	650	
Aluminum	660	

Table 3: Recrystallization temperature and melting points of selected metals

If aluminum or magnesium are clad to high purity nickel, the composite can be soft annealed.

From 500 °C upwards, nickel tends to stick, requiring strip annealing. As high purity nickel recrystallizes below 500 °C, it can be bell annealed. Bell annealing is more economical than continuous annealing.

IV. Function as diffusion barrier

If clad metals are exposed to elevated temperatures, its layers may diffuse into each other. This is the case for copper and gold, especially, when the gold layer is electrolytically deposited and therefore porous. In addition, constituents of layers may migrate from one layer into another. This happens with C, if high carbon steel and low carbon steel are cladded. Nickel can be used as an interlayer hindering diffusion.

Examples of the use of nickel (whether as electrolytically deposited or clad layer) are listed in the following table. Compared with electrolytically deposited layers, clad layers have the following advantages:

- clad layers are pore free. Electrolytically deposited layers must have a minimum thickness of about 5 µm to be pore free.
- Electrolytically deposited layers are hard and tend to flake off. To increase bonding strength, diffusion annealing is applied, where applicable (e.g. deep drawn battery shells).

Product	Metal 1	Metal 2	Diffusion
Low current contacts (dry contacts)	Copper or Zinc	Gold or Palladium	Cu diffuses through Au and oxidizes; thereby, the contact resistance increases. Ni also diffuses through Au, but very slow; in addition, Ni does not oxidize in the typical temperatures of application. Up to 500 °C only slow diffusion between Ni and Cu occurs.
Plain (slide) bearings	Copper from leaded bronze	Tin	Composite Bearings: Hindering the development of brittle Copper-Tin-Phases
Brazed joints	Titanium	Iron	Ni-Interlayer hinders diffusion of Ti in Fe
Hightem-perature-protection	Iron	Molybdenum, Tungsten	Delamination caused by the origination of brittle intermetallics: Fe_7Mo_6 and Fe_7W_6
Explosion-clad composite	Steel	Aluminum	Origination of brittle Al-Fe intermetallics

Table 4: Interdiffusion between metals

B. Applications

I. Clad metals

Pure nickel is used as protection layer in high temperature, highly corrosive environments as:

- Interconnect in SOFC and MOFC

Pure nickel, clad to aluminum or magnesium, can be soft annealed. NiAl is used as a transition metal to contact battery cases made from aluminum to copper and nickel leads.

II. Brazing

Nickel is used for brazing in form of foil, expanded metal/metal mesh and layered or clad composite. Nickel functions as solder and spacer to take up stress. Nickel is used as braze material in the following applications:

Layered or clad metals to braze *metals*:

Partner 1	Partner 2	Application	Metal combination
Aluminum	Aluminum	Heat exchanger	AlSi/Ni
Titanium	Titanium	Honeycomb structure	Ni/Ti/Ni on SS-core
Titanium alloy	Titaniumalloy		Ni/Kovar/Cu
Titanium	Stainless Steel	Implantable device	Ni/Ti/Ni
Tool Steel	Soft Steel	Paper cutter	Ni/Cu/Ni
Stainless Steel	Stainless Steel	EGCR-Cooler	Ni/Cu
Stainless Steel	Stainless Steel	Heat exchanger	Ni/Ti/Ni
Tungsten	Copper	Heat exchanger	Ti/Ni/Ti

Table 5: Metal combinations to braze metals

Layered or clad metals to braze *ceramics*:

Partner 1	Partner 2	Application	Metal combination
Ceramic	Metal	Vacuum tight joint	Ni/Ti/Ni
Zirconium	Titanium	Implanted device*	Ni/Ti50Zr/Ni
Zirconium	Stainless Steel	Implanted device*; Electrolyte in SOFC	Ni/Ti/Ni
γ-TiAl			Ti/Ni/Ti
Aluminum-oxide	Kovar		Ni/Ti/Ni
SiC	Ni-alloy	Turbines	Ni/Kovar/Cu
Si3N4	Inconel 718	Turbines	Ti/Cu/Ni

* Nickel can be used as solder for implants, if nickel is chemically bound.

Table 6: Metal combinations to braze ceramics

III. Thermobimetals

Thermobimetals are composites consisting of a layer with a high and a layer with a low coefficient of thermal expansion. In a two layer composite, the layer with the high coefficient of expansion may consist of nickel, e.g. ASTM B388-06 and TM22. In case of a three layer structure, an intermediate layer consisting of copper or nickel is used either to reduce the electrical resistance or to increase thermal conductivity. For interlayers of nickel see: ASTM B388-06 TM9 to TM17; DIN 1715, Tl. 1 TB 1425, 1435, 1555).

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