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Pure Nickel

Nickel Alloys

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Nickel Alloy Manufacturing Process

Nickel has been used in alloys that date back to the dawn of civilization. Nickel in elemental form or alloyed with other

Invar - Nickel Iron Alloy

Chemical Formula

Ni-Fe Alloy

Topics Covered

metals and materials has made significant contributions to our present-day society and promises to continue to supply materials for an even more demanding future.

Nickel is a versatile element and will alloy with most metals. Complete solid solubility exists between nickel and copper. Wide solubility ranges between iron, chromium, and nickel make possible many alloy combinations.

Background

Few people realise that the nickel-iron alloy, Invar, plays a crucial part in so many of their household controls and office appliances. This role was established soon after its discovery 100 years ago in 1896. Invar is the forerunner of a family of controlled expansion nickel-iron alloys which form the essential part of bimetals and thermostats. Invar itself is still used today in vast numbers of household appliances, from electric irons and toasters to gas cookers and fire safety cutoffs. In the office, computer terminals and TV screens make extensive use of Invar and other Ni-Fe alloys for shadow masks, frames, and cathode ray tube gun parts.

Other applications for these special alloys are continuing to be found in industry for advanced electronic components, filters in mobile phone networks and even as tank membranes for massive liquefied natural gas transport ships.

Discovery and Nobel Prize

When Invar was discovered in 1896, its unique property of low and linear expansion over a wide temperature range allowed the production of effective bimetals which could be used in safety cut-off devices for gas cookers and heaters. For his work on the nickel-iron system and the discovery of Invar, Charles Edouard Guillaume of Imphy was awarded a Nobel prize for Physics early in the 20th century.

One of the traditional uses for Invar has been for the thermostat of electric immersion heaters, used for a variety of domestic and commercial water heating systems. Operation of the thermostat is based upon differential expansion between a brass tube and an inner Invar rod, the resulting movement being used to actuate a microswitch. The set temperature is commonly adjustable in the range between 48-83°C.

Physical Properties

Invar is a 36% nickel iron alloy which has the lowest thermal expansion among all metals and alloys in the range from room temperature up to approximately 230°C. The Invar alloy is ductile and easily weldable, and machinability is similar to austenitic stainless steel. It does not suffer from stress corrosion cracking.

The mean coefficient of thermal expansion (CTE) of Invar from 20-100°C is less than 1.3 x 10^{-6}°C^{-1}. The Curie point is 230°C, and density is 8.1 $kg.m^{-3}$.

Current Uses of Nickel Iron Alloy Invar

Cathode Ray Tubes

Between the range -100 to +200°C Invar's CTE is very low. This feature is very useful for many specific applications in high tech industry. Cathode ray tubes for television and display screens are increasingly required to provide greater user comfort, with higher contrast, improved brightness and sharper definition. This progress has been made possible by the use of shadow masks made from Invar strip, with its low coefficient of thermal expansion allowing precise dimensioning of components even with changing temperature.

Other Applications

Other application areas, such as telecommunications, aeronautical and aerospace engineering, cryogenic engineering (liquefied natural gas tankers) etc, require either high dimensional stability with variation in temperature, or expansion characteristics matched with those of other materials, such as glass, ceramics, or composites.

The diversity of these requirements has led to the development of a wide range of Fe-Ni, Fe-Ni-Co and Fe-Ni-Cr alloys, in two major groups:

Low Expansion Alloys

These include Invar and N42. As electronic components become ever more miniature, the demands on the material used in their manufacture become ever more critical. The production of lead frames for example requires very close dimensional tolerances and high cleanliness combined with exceptional stamping or chemical etching performance. Grades of N42 have been specifically developed to match these requirements.

Sealing Alloys

These include other Fe-Ni grades, Fe-Ni-Co and Fe-Ni-Cr alloys. A full range of alloys have been produced to associate with the principal glasses supplied by major manufacturers including Schott, Corning, NEG and Ashai. These glasses used in electronics are chosen for specific physical, chemical or optical properties and the choice of the associated sealing metal depends on the glass and the type of seal (matched or compressive).

Future Uses

Appropriate solutions are needed to match the requirements created by technologies which are in rapid and perpetual evolution, and these could come from Invar and its nickel iron alloy derivatives.

Composite Manufacturing

Invar also has an important role to play in the future of composite manufacturing. The aerospace industry will make increasing use of composites for weight/strength improvements. The manufacturing process of composite multilayer structures involves moulding on tools which are then autoclaved. Tooling materials must provide temperature resistance, very low CTE to match the composite, vacuum integrity, thermal conductivity and machinability.

A single tooling material to meet all the requirements does not exist, but of all metallic and non-metallic (e.g. carbon fibre/epoxy) options, Invar provides one of the lowest CTEs of all, the major criterion. The compatibility of the CTE of the Invar mould and the composite parts avoids distortion, induced stress and warpage. Studies carried out by Boeing show that Invar is the material which will provide the best compromise between the most important requirements (like CTE and durability) and overall fabrication costs.

Property Table of Invar

Material	Invar - Nickel Iron Alloy					
Property	**Minimum Value (S.I.)**	**Maximum Value (S.I.)**	**Units (S.I.)**	**Minimum Value (Imp.)**	**Maximum Value (Imp.)**	**Units (Imp.)**
Atomic Volume (average)	0.0068	0.0071	m^3/kmol	414.961	433.268	in^3/kmol
Density	8.1	8.2	Mg/m^3	505.667	511.91	lb/ft^3
Energy Content	50	200	MJ/kg	5416.93	21667.7	kcal/lb
Bulk Modulus	106	112	GPa	15.374	16.2442	10^6 psi
Compressive Strength	240	725	MPa	34.8091	105.152	ksi
Ductility	0.06	0.45		0.06	0.45	
Elastic Limit	240	725	MPa	34.8091	105.152	ksi

Endurance Limit	185	405	MPa	26.832	58.7402	ksi
Fracture Toughness	120	150	$MPa.m^{1/2}$	109.206	136.507	$ksi.in^{1/2}$
Hardness	1200	2400	MPa	174.045	348.091	ksi
Loss Coefficient	0.0003	0.0011		0.0003	0.0011	
Modulus of Rupture	240	725	MPa	34.8091	105.152	ksi
Poisson's Ratio	0.28	0.3		0.28	0.3	
Shear Modulus	54	58	GPa	7.83204	8.41219	10^6 psi
Tensile Strength	445	810	MPa	64.5418	117.481	ksi
Young's Modulus	137	145	GPa	19.8702	21.0305	10^6 psi
Glass Temperature			K			°F
Latent Heat of Fusion	270	290	kJ/kg	116.079	124.677	BTU/lb
Maximum Service Temperature	600	700	K	620.33	800.33	°F
Melting Point	1690	1710	K	2582.33	2618.33	°F
Minimum Service Temperature	0	0	K	-459.67	-459.67	°F
Specific Heat	505	525	J/kg.K	0.390798	0.406276	BTU/lb.F
Thermal Conductivity	12	15	W/m.K	22.4644	28.0805	$BTU.ft/h.ft^2.F$
Thermal Expansion	0.5	2	10^{-6}/K	0.9	3.6	10^{-6}/°F
Breakdown Potential			MV/m			V/mil
Dielectric Constant						
Resistivity	75	85	10^{-8} ohm.m	75	85	10^{-8} ohm.m

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

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