INVAR 36

Typical Analysis in Percent:

Ni	36.00	Cr	0.25
Mn	0.50	Si	0.25
Al	0.10	Mg	0.10
Zr	0.10	Ti	0.10
P	0.02	S	0.02
Fe	Balance		

Typical Tensile Strength (1000 psi):

Annealed:	85 Maximum
¼ Hard:	90 to 115
½ Hard:	105 to 125
Hard:	120 Minimum

Typical Hardness, Rockwell B:

Annealed:	70 Maximum
¼ Hard:	78 to 83
½ Hard:	84 to 88

Typical Coefficient of Thermal Expansion:

Temp. Range	in/in/ °F x 10^{-6}
-200 - 0 °F	1.1
0 - 200 °F	0.7
200 - 400 °F	1.5
400 - 600 °F	6.4
600 - 800 °F	8.6
800 - 1000 °F	9.5

Physical Properties (Annealed):

Specific Gravity: 8.08
Density: 0.292 lb/in
Electrical Resistivity: 494 ohms/mil/ft
Temperature Coefficient of Electrical Resistivity: 0.67 x 10^{-3}/°F
Melting Point: 2600 °F
Curie Temperature: 530 °F
Inflection Temperature: 375 °F

General Characteristics:

Invar is an iron-nickel austenitic alloy of lowest thermal expansivity. It is strong, tough, ductile and possesses a useful degree of corrosion resistance, it is magnetic at temperatures below its Curie point and non-magnetic at temperatures above. Invar is therefore always magnetic in the temperature range in which it exhibits the low expansion characteristics. Invar is the standard alloy for low expansivity up to 400 °F. For applications at higher temperatures, the higher nickel alloys are recommended.

The effect of heat treatment upon the expansion of the alloy is dependent upon the method of cooling. Rapid cooling (quenching) decreases the rate of expansion while the reverse is true when slow cooling is employed. Cold working is even more effective than quenching in lowering the expansivity. Subsequent annealing will remove the lowering of the coefficients induced by cold work in proportion to the temperatures employed, the alloy assuming the values corresponding to the annealed condition when a temperature of about 1100 ^{o}F is reached. Invar which has been subjected to cold working or machining may require a stress-relieving heat treatment for stabilization if the material is to be used for high precision work. This material is never used above its thermal inflection point.

<u>Heat Treatment</u>:

Anneal: The alloy softens progressively when heated in the range of 1000 to 2300 ^{o}F. Pronounced grain growth does no occur until 1900 ^{o}F has been passed. It can be air cooled or water quenched from the annealing temperature.

Stress Relieve: Heat to 600 - 700 ^{o}F for about one hour, air cool, reheat to a temperature somewhat above the top operating temperature, cool slowly to somewhat below the lower operating temperature, again heat slowly to above the operating temperature, cool slowly to room temperature (cooling very slowly through the Curie temperature is also considered to improve stability).

Harden: Cannot be hardened by any thermal treatment.
Stabilize: Water quench from 1500 ^{o}F, then age for one hour at 600 ^{o}F, air cool.

<u>Machinability</u>:

Being tough and ductile, it is somewhat difficult to machine. High speed steel or sintered carbide should be used and the cutting edges kept sharp. The machinability characteristics of Invar are quite similar to austenitic stainless steels. Because of its high ductibility, the chips formed during machining tend to be stringy and tough, thus imposing rapid wear on cutting tool edges. In general, slow speeds and light feeds should be used to avoid excessive heat and minimize the possibility of the generated heat affecting the expansion characteristics. The use of soluble oil cutting compound is recommended for all machining operations.

<u>Workability</u>:

Can be strengthened and hardened somewhat by cold work, although it does not work harden as rapidly as the stainless steels. It has almost unlimited capacity for plastic deformation, either hot or cold. Therefore, it can be heated or cooled at any rate without danger of rupture. Hot working can be done at any temperature below 2300 ^{o}F. Exposure at high temperature to sulphur bearing gases causes poor hot working qualities. Cold working hardens the alloy to a maximum of about Rockwell C32.

Forging: The principal precaution to observe in forging is to heat quickly and avoid soaking in the furnace. Long soaking may result in a checked surface due to absorption of sulfur from the furnace atmosphere and/or oxide penetration. A forging temperature of 2000 - 2150 ^{o}F (1100 - 1180 ^{o}C) is preferred. Invar 36 may also be swaged and cold upset.

Blanking and Forming: Alloy 36 presents no unusual problems in blanking and forming. For cleanest blanking properties, a Rockwell hardness of B90 is suggested. This hardness will allow mild bending and forming operations. Where deep drawing operations are involved a finish annealed strip of a Rockwell harness of about B75 is usually desirable.

Grinding: A silicon carbide wheel is desirable, preferably a soft wheel which will wear without loading. For finish grinding, a satisfactory grade to start with is No. 80 grit.

Welding: Alloy 36 can be welded by the conventional methods. Caution must be taken so as not to overheat the molten metal. This will avoid spattering of the molten metal and pits in the welded area. When welding with rod, it is essential that the rod be of the same composition if similar properties in the weld are desired; otherwise mild steel rods or 18-8 stainless steel rods may be employed. The rods should be heavily coated. In oxyacetylene welding, the flame is maintained slightly on the reducing side. An Invar welding wire with a higher titanium and manganese content minimizes weld hot-cracking in heavy gages. Either the gas metal arc (MIG) or gas tungsten (TIG) process can be used with this wire.

Brazing: Silver and zinc-free alloys have been used for brazing Invar 36. This alloy should be annealed prior to brazing. Joints should be designed to avoid placing material in tension during brazing. If silver soldering is done manually, the parts should be preheated to 800 ^{o}F and slowly cooled.

Plating: Alloy 36 can be chromium, cadmium and nickel plated or zinc coated by the usual methods used for ferrous alloys.

Pickling: Pickling is best done in hydrochloric acid solutions. A 25% solution at 160 ^{o}F is particularly effective.

Distortion: Although best properties with respect to expansion coefficient are reported after a water quench, thin sections should be cooled rapidly in air to avoid distortion. Invar has poor heat conductivity, a low coefficient of expansion at temperatures below 300 ^{o}C, normal coefficient of expansion at higher temperatures, and an elastic modulus 79% of steel. These conditions promote internal strain and distortion. Note carefully the section on stress relief. We suggest a rapid air cool instead of a water quench whenever possible.