



ArcelorMittal

# INVAR<sup>®</sup> M93

## CONTROLLED EXPANSION ALLOY

All the properties given below are for the annealed condition. Please consult us for any specific characteristics related to particular applications.

### CHEMICAL COMPOSITION

Ni	C	Si	Mn	S	P	Fe
35-36.5	≤ 0.04	≤ 0.25	0.2-0.4	≤ 0.0015	≤ 0.008	Bal.

### PHYSICAL PROPERTIES

Expansion coefficient	
Temperature (°C)	Mean CTE (10 <sup>-6</sup> /°C)
-180 to 0	1.5
-120 to 0	1.4
- 60 to 0	1.1
0 to 100	1.3
0 to 200	2.5
0 to 300	5.2

Other properties	
Density	8.125 (g/cm <sup>3</sup> )
Curie point	240 °C
Young's modulus at 20°C	142 000 MPa
Young's modulus at -160°C	136 000 MPa
Shear modulus at 20°C	57 000 MPa
Shear modulus at -160°C	52 000 MPa
Mean specific heat between -196°C and 20°C	0.385 J. g <sup>-1</sup> .K <sup>-1</sup>
Thermal conductivity at 20°C	0.147 J. cm <sup>-1</sup> .s <sup>-1</sup> .k <sup>-1</sup>
Thermal conductivity at -160°C	0.084 J. cm <sup>-1</sup> .s <sup>-1</sup> .k <sup>-1</sup>
Electrical resistivity at 20°C	80 μΩ.cm
Electrical resistivity at -196°C	50 μΩ.cm

Units : 1 J = 0.48 10<sup>-4</sup> B.T.U. = 0.24 cal

## MECHANICAL PROPERTIES

	Cold rolled strip			Hot rolled strip		
	0.2% YS (MPa)	UTS (MPa)	Elongation (%)	0.2% YS (MPa)	UTS (MPa)	Elongation (%)
at 20°C	≥ 280 (320)	≥ 470 (510)	≥ 30 (40)	≥ 280 (320)	≥ 450 (490)	≥ 30 (40)
at -196 °C	(680)	(980)	≥ 30 (40)	(650)	(920)	≥ 30 (40)

(... ) indicative typical values.

## FORMABILITY

In addition to high tensile elongation values, the properties shown below (impact strength, bendability) show that the ductility of l'INVAR® M93 remains excellent at cryogenic temperatures, like at ambient temperature.

### ➤ Charpy impact strength (J/cm<sup>2</sup>)

at 20°C	≥ 200 (300)
at -196°C	≥ 120 (200)

(... ) indicative typical values.

### ➤ Phase stability

The absence of embrittlement at cryogenic temperatures is guaranteed by the perfect stability of the austenitic crystal structure and has been verified by performing tensile and Charpy V-notch impact tests after holding at -196°C. Similar results have been obtained after holding in liquid helium (4 K).

### ➤ Bending

Thickness (mm)	Mandrel diameter (mm)	Bending angle	Result
0.5	0.25	90 °	No cracking
1.5	0.80	90 °	No cracking
6	34	180 °	No cracking
12	64	180 °	No cracking

## WELDABILITY

Because of its specially optimized chemistry, **INVAR**<sup>®</sup> M93 has excellent weldability. It can be readily welded by all common techniques, such as resistance spot and seam welding, TIG, MIG, plasma and laser welding. **INVAR**<sup>®</sup> M93's chemical composition and its carefully controlled manufacturing process guarantee the absence of all risk of solidification or reheating cracks. This has been abundantly verified by numerous cross bead tests (CBT). For all information concerning the welding specifications and the mechanical properties of weld joints, please consult us or refer to the brochure « **INVAR**<sup>®</sup> M93 tube for cryogenic applications – welding processes ».

## FATIGUE STRENGTH

Fatigue tests have been performed in both the alternating bending and tension-tension modes on cold rolled strip specimens in the annealed condition. The table below gives the fatigue endurance limit at  $10^7$  cycles :

	Alternating bending (MPa)	Fluctuating tension ( $\sigma$ min = 0.1 $\sigma$ max)
at 20°C	210	$\sigma$ max = 320
at -196 °C	400	$\sigma$ max = 540

These results have been confirmed by values obtained on bar specimens subjected to bending, torsion, tension-tension and compression testing.

## OTHER PROPERTIES

Effect of grain size on mechanical properties			
ASTM grain size	Vickers hardness	0.2% YS (MPa)	UTS (MPa)
10	155	340	
8	145	300	
6	140	290	

Strain hardening				
% cold reduction	0	15	25	50
Vickers hardness	140	200	215	230