

# INVAR®

## CONTROLLED EXPANSION ALLOYS

(Alloy developed by Imphy in 1896. Registered trademark)

### INTRODUCTION

Invar® is a Fe-Ni alloy with a 36% nickel content that exhibits the lowest expansion of known metals and alloys from the lowest temperatures up to approximately 230°C.

It is used in particular for:

- thermostat rods
- clock balance wheels
- precision condenser blades
- radar cavity resonators
- moulds for composites
- metrology applications, monitoring of civil engineering structures
- seals, spacers and specialised frames
- the manufacture of thermal bimetallic strips
- integral holds on gas carriers (M93)
- liquefied gas transfer lines (M93)
- television applications: Shadow Mask, frames, suspensions, electron gun components.
- electronic applications: special electronic housings.

### TYPICAL ANALYSIS

The Fe-Ni alloys in the Invar® range developed by ArcelorMittal-Stainless & Nickel Alloys feature optimised chemical compositions in order to achieve the best balance between expansion and the other properties required by the applications: mechanical properties, weldability, structural stability at cryogenic temperature, etc.

The content by weight of the principal chemical elements is given in the table below.

Grade	Ni	Co	Fe
Invar® & GSP Invar®	36	< 0.5	remainder
Invar®-M93	36	< 0.2	remainder
Inovar	36	< 0.1	remainder
Microvar	36	0.25	remainder
Inovco	33	4.5	remainder
Hardened Invar®	40.5	< 0.4	remainder

## GRADES

The Invar<sup>®</sup> grades developed by ArcelorMittal-Stainless & Nickel Alloys can be categorised into seven groups:

		<b>Typical values</b>
<b>INVAR<sup>®</sup></b> (Standard Invar <sup>®</sup> quality dedicated to etching)	$\alpha_m$ between 20° and 100°C	$1.2 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$
<b>GSP INVAR<sup>®</sup> (1)</b> (Invar <sup>®</sup> quality dedicated to machining and stamping)	$\alpha_m$ between 20° and 100°C	$1.2 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$
<b>INVAR<sup>®</sup>-M93</b> (Cryogenic Invar <sup>®</sup> with improved weldability)	$\alpha_m$ between -180° and 100°C <i><math>\alpha_m</math> between 20° and 100°C</i>	$1.5 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$ $1.3 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$
<b>INOVAR</b> (Invar <sup>®</sup> with low residuals, low expansion coefficient)	$\alpha_m$ between 20° and 100°C	$0.65 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$
<b>MICROVAR (2)</b> (Inovar with low cobalt content and enhanced mechanical properties)	$\alpha_m$ between 20° and 100°C	$0.65 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$
<b>INOVCO (2)</b> (Invar <sup>®</sup> with cobalt, very low expansion coefficient and enhanced mechanical properties)	$\alpha_m$ between 20° and 100°C	$0.55 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$
<b>HARDENED INVAR<sup>®</sup> (2)</b> (Invar <sup>®</sup> with elevated mechanical properties, hardened by precipitation of the $\gamma'$ -Ni <sub>3</sub> (Ti, Al) phase)	$\alpha_m$ between 20° and 100°C	$2.75 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$

NB: Measurements are conducted after heat treatment at 950° for 30 minutes followed by cooling in air. On hardened Invar<sup>®</sup>, the measurements are conducted following hardening heat treatment at 750°C. Other types of measurement / treatment are possible on request

(1) This new grade dedicated to stamping is available in different cold rolled gauges with a finer grain size in order to improve pressing behaviour (Typical grain size :  $G_{ASTM} = 10$ ).

(2) These products are only supplied for use on specific projects.

## **TYPICAL PHYSICAL PROPERTIES**

Only Invar<sup>®</sup> and hardened Invar<sup>®</sup> exhibit significantly different physical properties to those of Invar<sup>®</sup>. This divergence is due to the addition of chemical elements (Co, Ti).

Invar <sup>®</sup> Grade	Curie Temperature (°C)	Melting point (°C)	Resistivity at 20°C (μW.cm)	Thermal conductivity at 20°C (W.m <sup>-1</sup> .°C <sup>-1</sup> )	Specific heat at 20°C (J.kg <sup>-1</sup> .°C <sup>-1</sup> )	Density (g.cm <sup>-3</sup> )
Invar <sup>®</sup> & GSP Invar <sup>®</sup>	230	1450	75	10.5	510	8.1
Invar <sup>®</sup> -M93						
Inovar						
Microvar						
Inovco	220	1470	80	10.5	510	
Hardened Invar <sup>®</sup>	220	1410	80	14.1	490	

The Fe-Ni alloys in the Invar<sup>®</sup> range are characterised by a mean expansion coefficient, close to ambient temperature, of less than  $3.5 \times 10^{-6} \text{ } ^\circ\text{C}^{-1}$ . The low expansion of these alloys is only observed below the Curie temperature.

Mean expansion coefficient  $\alpha_m 10^{-6} \text{ } ^\circ\text{C}^{-1}$

	-180°C	20°C to 100°C	20°C to 200°C	20°C to 300°C	20°C to 400°C	20°C to 500°C
Invar <sup>®</sup> & GSP Invar <sup>®</sup>	1.8	1.2	2.3	4.8	7.5	8.9
Invar <sup>®</sup> -M93	1.5	1.3	2.4	4.9	7.6	9
Inovar	1.4	0.65	1.9	4.8	7.6	9.6
Microvar	1.4	0.65	1.7	4.6	7.5	9.5
Inovco		0.55	1.5	4.4	7.3	9.3
Hardened Invar <sup>®</sup> <sup>(1)</sup>	4.5	2.8	4	6.5	9	10.5

<sup>(1)</sup> : Hardened at 750°C for 30 minutes, from an annealed supply condition.

## TYPICAL MECHANICAL PROPERTIES FOR COLD-ROLLED PRODUCTS

The Fe-Ni alloys in the Invar<sup>®</sup> range exhibit mechanical properties in the range 250 MPa – 1000 MPa. Control of residual chemical elements and the fine-grained austenitic structure of these grades endow them with excellent ductility (elongation at fracture and impact strength).

Grade	Annealed - 850°C - 15 mins					Strain-hardened 25%		
	Rp <sub>0.2%</sub> (MPa)	Rm (MPa)	E (MPa)	A (%)	Grain size (ASTM)	Rp <sub>0.2%</sub> (MPa)	Rm (MPa)	A (%)
Invar <sup>®</sup> & GSP Invar <sup>®</sup>	260	455	130 000	> 30	8	560	575	> 5
Invar <sup>®</sup> M93	270	465			8	570	580	
Inovar	260	455			8	560	570	
Microvar	290	470			9	600	630	
Inovco	300	480	125 000		8	610	650	
Hardened Invar <sup>®</sup>	<sup>(1)</sup> 300 <sup>(2)</sup> 775	<sup>(1)</sup> 580 <sup>(2)</sup> 1100	155 000	<sup>(1)</sup> 33 <sup>(2)</sup> 15	8	<sup>(3)</sup> 750 <sup>(4)</sup> 950	<sup>(3)</sup> 775 <sup>(4)</sup> 990	<sup>(3)</sup> 7 <sup>(4)</sup> 6

<sup>(1)</sup> : Annealed supply condition.

<sup>(2)</sup> : Hardened at 750°C for 30 minutes, from an annealed supply condition.

<sup>(3)</sup> : Strain-hardened supply condition.

<sup>(4)</sup> : Hardened supply condition.

Temperature (°C)	Invar <sup>®</sup> / Inovar Annealed - 850°C - 15 mins				Invar <sup>®</sup> / Inovar Strain-hardened 25%			Hardened Invar <sup>®</sup> <sup>(1)</sup>			
	Rp <sub>0.2%</sub> (MPa)	Rm (MPa)	E (MPa)	A (%)	Rp <sub>0.2%</sub> (MPa)	Rm (MPa)	A (%)	Rp <sub>0.2%</sub> (MPa)	Rm (MPa)	E (MPa)	A (%)
20	260	455	130 000	30	560	575	7	775	1100	155 000	15
100	210	410	135 000	32	550	565	5.5	750	1050	159 000	15
200	130	350	142 000	33	510	550	3.5	660	1000	165 000	18
300	100	325	146 000	33	480	485	3	630	950	170 000	20
400	90	290	143 000	35	410	430	3.5	620	900	165 000	20
500	85	260	140 000	35	310	340	9	600	860	160 000	20
600	75	210	137 000	35	240	275	18	580	730	150 000	15
700	73	130	134 000	30	90	130	30	520	560	145 000	10

<sup>(1)</sup> : Hardened at 750°C for 30 minutes, from an annealed supply condition.

## TYPICAL MECHANICAL PROPERTIES FOR HOT-FINISHED INVAR® PRODUCTS

The physical properties are measured in the recrystallised condition

	Grain size	Vickers hardness HV30	Rm (MPa)	Rp0.2%(MPa)	A% (50 mm)
	ASTM E-112	NF EN ISO 6507	NF EN ISO 10002-15	NF EN ISO 10002-15	NF EN ISO 10002-15
<b>Round - Disc</b>					
20 < $\phi$ < 500 mm	3 à 10	130 – 220	400 – 550	200 – 350	> 20
As-rolled					
<b>Rod</b>					
$\phi$ < 20 mm		150 – 250	650 – 850		> 5
As-drawn					
<b>Plate</b>					
3 < Thick < 100 mm		100 – 150			
Annealed					
<b>Flat - Square</b>					
3 < Thick < 30 mm		100 – 150			
Annealed or As-drawn					
<b>Ring</b>					
As-rolled		> 110			
<b>Billet</b>					
<b>Block</b>					
<b>Sheet bar</b>					

NB: Other tests can be performed on request

## TYPICAL MAGNETIC PROPERTIES

			B <sub>10</sub> (G)	Hc (A/m)	$\mu_{max}$	$\mu_{anh}$ at 0.4 Oe
<b>Grade</b>	Invar®	Annealed 850°C - 15 mins	12 500	27	9 500	18 000
	Inovar			25	12 000	19 000
	Microvar			45	6 000	13 500
	Inovco			43	6 300	14 000
	Hardened Invar®	Hardened on annealed supply condition (750°C - 30 mins)	11 750	38	4 900	9 000

$\mu_{anh}$ : anhysteretic permeability

## SUPPLY FORMS

Cold-rolled products

Strip  
Plate

Hot-finished products

Round - Disc  
Rod  
Plate Flat – Square  
Ring  
Billet – Block – Sheet bar

## PROCESSING PARAMETERS

- Consult us in respect of Microvar and hardened Invar<sup>®</sup>.
- For Invar<sup>®</sup>, Inovar and Inovco:

### Machining

	Turning	Milling	Drilling
<b>Tool</b>	Carbide S3 or 34	Super HSS	High speed steel
<b>Coolant/Lubricant</b>	Soluble oil	Soluble oil	Soluble oil
<b>Cutting angle</b>	12 – 17°	15°	
<b>Relief angle</b>	5 – 8°	3 – 7°	9 – 13°
<b>Cutting speed (m/min)</b>	50 – 75	10 – 15	10
<b>Feed rate mm/</b>	0.2 – 0.5 /revolution	0.05 – 0.10 /tooth	0.10 /revolution

### Brazing:

In order to avoid any risk of stress corrosion cracking when brazing, the parts to be joined must be free from residual stresses. This condition is attained by stress-relief annealing at 700-800°C. Brazing with copper or sil ver-copper with or without palladium produces very good results on stress-relieved Invar<sup>®</sup>. The use of tin or white tin soft-brazing solder can also be adopted.

### Welding:

Welding should preferably be carried out in the annealed condition. Oxy-acetylene, TIG and resistance welding can be performed, taking the same type of precautions as for stainless alloys.

For complex fabricated joints (intersecting welds) and for thicknesses in excess of 2 mm, it is possible, depending on the application requirements, to use either Invar<sup>®</sup>-M93, Invar<sup>®</sup>-M93T or Invar<sup>®</sup>-Ti.Mn wire (consult us).

Refer to the specific welding technical data sheets for Invar<sup>®</sup> M93 and M93T.

### Baking Invar<sup>®</sup> :

- For stress relief: Rolled, drawn, forged, machined, etc. products generally exhibit residual stresses. In the case of high-precision machining with substantial material removal, it is recommended that a stress relief treatment for 3 hours at 315°C followed by slow cooling be performed between rough and finish machining.
- For accelerated aging: Furthermore, Invar<sup>®</sup> is subject to some dimensional instability due to physico-chemical effects. It is therefore necessary to perform accelerated aging of the metal before use, by baking as follows: 24 hours at 100°C followed by slow cooling to ambient temperature (25°C/24h).

### Corrosion resistance:

Despite its high nickel content, which affords it some resistance to oxidation, the Invar<sup>®</sup> alloy cannot be compared, as regards corrosion resistance, to so-called stainless alloys such as type 18/8 alloys for example. Careful polishing significantly improves its resistance to oxidation. Obviously, it is possible to employ the traditional methods of protection (varnishing, electroplating).