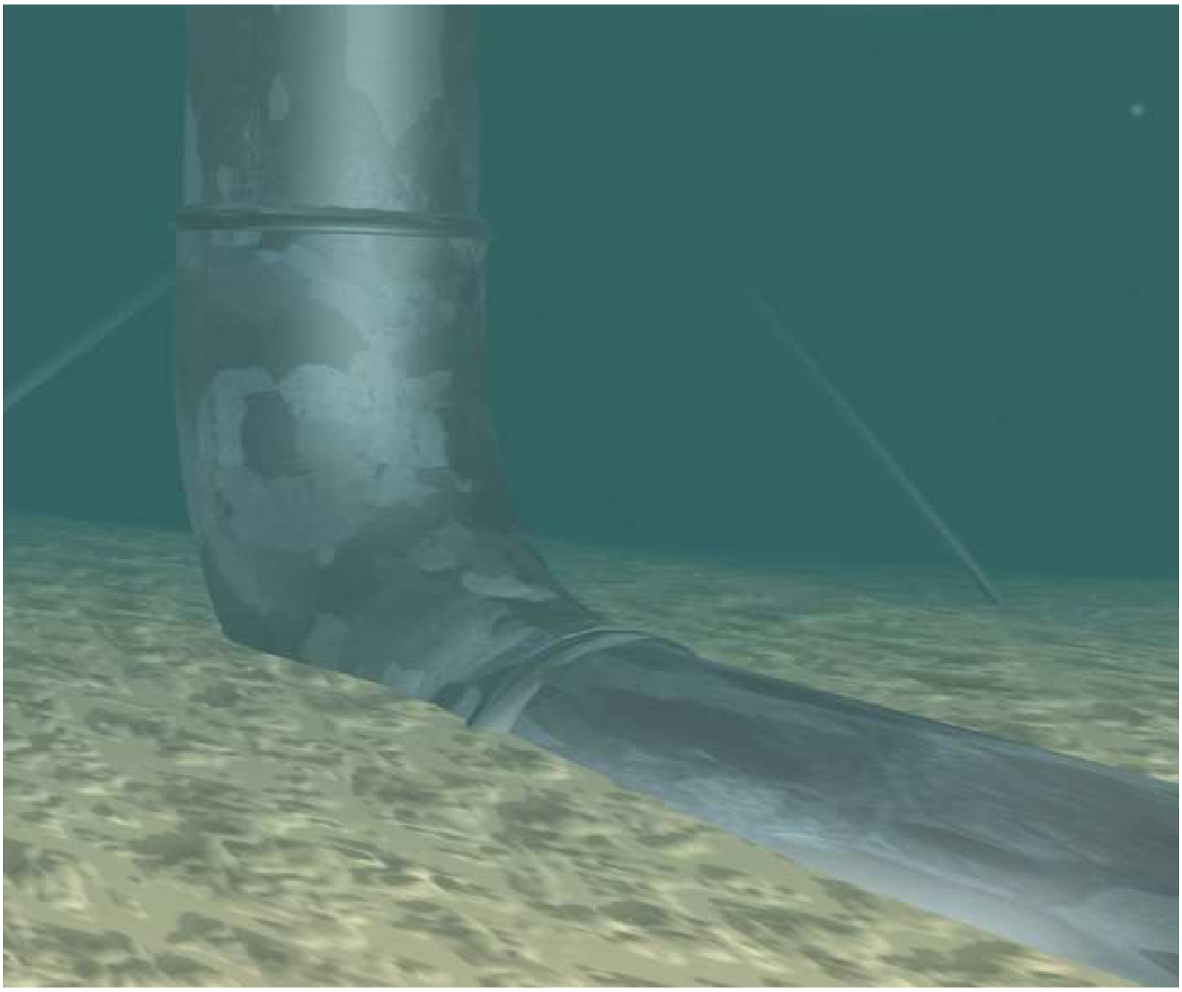
INVAR® M93

PIPES AND TUBES FOR LNG TRANSFER LINES

WELDING PROCESSES



ArcelorMittal

Stainless & Nickel Alloys

Being with LNG from the start of their venture in the 1960s, ArcelorMittal - Stainless & Nickel Alloys has always strived to be proactive in the market place and adjust to the needs of our customers.

ArcelorMittal - Stainless & Nickel Alloys is currently world leader (95% market share) in the supply of Invar® M93, producing LNG vessel tanks using the GTT N096 technology. We draw on this know-how to broaden our experience in cryogenics.

Thus today, we have the technical ability to offer Invar® M93 plates or coils for tubes, in a wide range of sizes, to meet the requirements of simple and economic construction of transfer lines for all kind of cryogenic liquids, such as LNG.

The main principle is to use the thermal coefficient value of Invar® M93 to simplify the construction of these cryogenic lines, to eliminate all thermal expansion compensation systems such as bellows or lyres, which are used to absorb the dimensional variations caused by temperature fluctuations of stainless steel pipes.

It follows that the economic savings are mainly obtained through being able to avoid the expansion compensation systems and by a reduction in the amount of welding and insulation required. This solution, by reducing loss of pressure, leads to reduction in tube diameter.

In the case of loading and unloading LNG, between the storage tanks and the LNG vessels, the infrastructure costs will be substantially reduced, thanks to replacing the stainless pipes laid along the dockside with pipes containing Invar® M93 internal tube directly onto the sea-bed.

Today we can offer to the tube manufacturers plates and coils in a wide range of sizes allowing the production of tubes with diameter ranging from 0.39” (10 mm) to 36” (914.4 mm) and thickness ranging from 0.02” (0.5 mm) to 0.75” (19.05 mm) with 6 or 12 meters current length.

Please consult us for further information regarding available sizes.

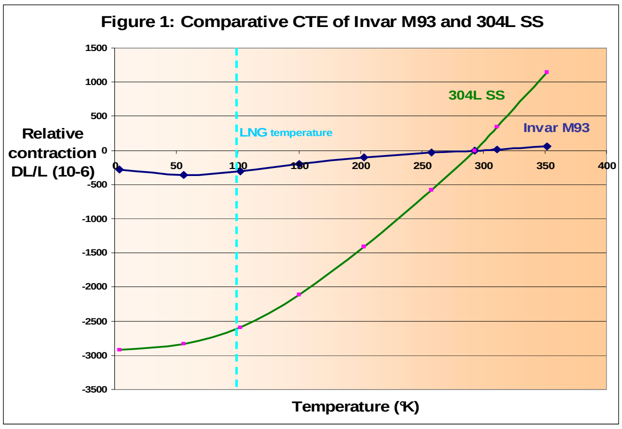
THE INVAR® M93 GRADE

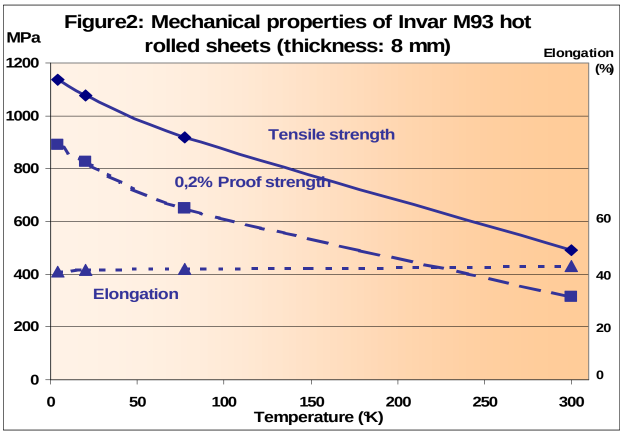
Invar® M93 gives a perfect answer to the needs, in terms of physical and mechanical properties, of all kind of cryogenic applications down to liquid helium temperature (4°K).

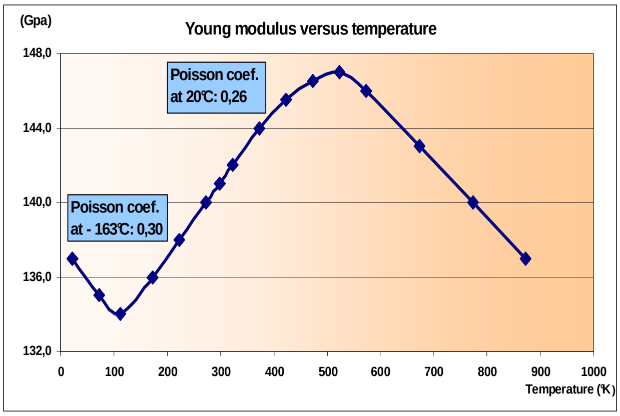
Indeed, all the properties which make Invar® M93 a success in the LNG world, have been confirmed down to 4°K:

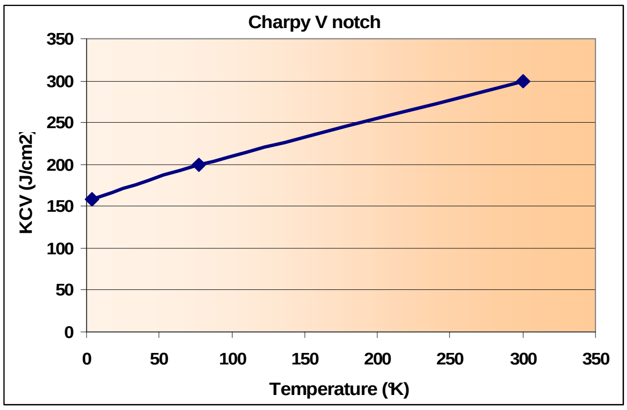
- very low thermal expansion coefficient,
- low Young modulus,
- very good mechanical behaviour combined to a high ductility.

(See figures 1 to 3 giving physical and mechanical properties variation versus temperature in the case of 8 mm thick sheets in annealed conditions).









Thanks to its fully austenitic structure at all temperatures, Invar® M93 has good ductility and toughness and consequently, offers good formability (deep drawing, folding, bending, etc…) without any risk of embrittlement when at cryogenic temperature, even in the case of high deformation rate made at room temperature. The austenitic structure also makes the welding operations easier during tubes fabrication and tubes assembly.

WELDABILITY

Invar® M93 weldability cannot be challenged. The number of LNG vessels built following to the GTT double Invar membrane technology represents close to 20 000 km of welds.
This experience combined with continuous R&D works gives a grade perfectly adapted to all welding processes such as automatic and manual GTAW (Gas Tungsten Arc Welding), GMAW (Gas Metal Arc Welding), PAW (Plasma Arc Welding), laser welding….
Invar® M93 is also perfectly adapted to all kinds of welding configurations: butt-welding (circular or orbital), cross bead welding, mono or multi layers welding, homogeneous welding, heterogeneous welding …

The chemical composition and the casting process provide Invar® M93 with unique properties and excellent weldability. It guarantees the absence of tendency to crack during solidification and more specifically during reheating (case of cross bead welding and multi layers welding). It makes it possible to use high-speed automatic welding equipment.

The process of eliminating chemical impurities which lead to reheat cracking (sulfur, phosphorus, aluminum, boron and nitrogen) allows Invar® M93 to be welded either without filler metal or with filler metal.

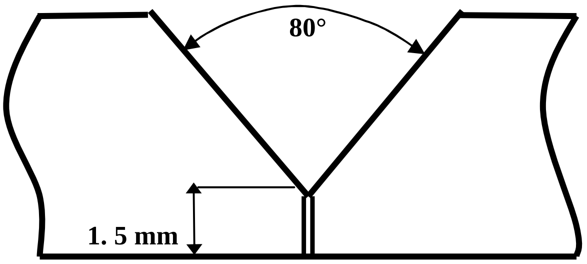
In order to meet the requirement regarding the overmatching of mechanical properties of the weld compared to base metal, ArcelorMittal – Stainless & Nickel Alloys, after testing different wire solutions, has developed a new grade for filler metal. This iron-nickel alloy with added titanium is called **Invar® M93 T** and gives higher tensile strength while ductility remains at a high level, similar to that of base metal (toughness ≈ 200 J/cm2). The chemical composition of this new filler metal have been defined to achieve the very best compromise in terms of performance required by cryogenic applications. (Chemistry with the same mastering of detrimental impurities allowing to obtain welds with improved mechanical properties, CTE as low as possible, same toughness and same fatigue behaviour than the base metal)

Nevertheless, when the overmatching of mechanical properties is not required, it remains advantageous to process with homogeneous welding. Indeed, Invar® M93 filler metal is the only grade able to guarantee the perfect continuity of the physical properties between the base material and its welded joint whatever the temperature range.

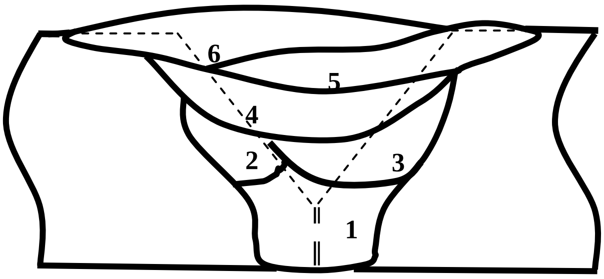
TESTING OF DIFFERENT WELDING WIRE SOLUTIONS: PROCEDURE QUALIFICATION RECORD

The following example shows the welding conditions we have determined for automatic GTAW of 8 mm thick Invar® M93 sheets in order to highlight the increase of mechanical properties given by the use of the different filler metals tested.

Preparation and number of layers:



After machining and before welding



After welding

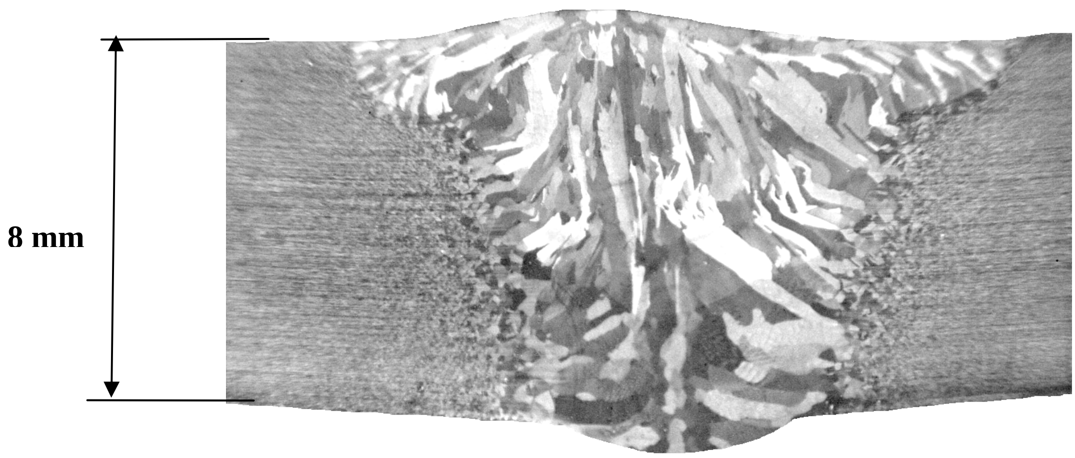
Welding parameters:

Weld layers number	1	2 to 6
Filler metal : diameter (mm)	-	1,2
Shielding gas flow rate (Ar + 5% H_2) (l/mn)	18	18
Backing gas flow rate (Ar 100%) (l/mn)	12	-
Current type	Pulsed	String
Current level (Amps)	143*	180
Voltage (V)	12,7	11,2
Welding speed (cm/mn)	8	25
Wire speed (cm/mn)	-	130
Heat input (KJ/cm)	13,6	4,8

* Pulsed current : pulse = 360 A, time = 100 ms
Base = 35 A, time = 200 ms

Inter-pass temperature: 150℃ maximum.
Initial and inter-pass cleaning by grinding.

Macrostructure of the weld made in using Invar® M93 T filler metal:



MECHANICAL AND PHYSICAL PROPERTIES OF WELDS

There are several ways to harden iron-nickel alloys such as Invar® M93, but in order to have the simplest solution without any additional heat treatment, ArcelorMittal – Stainless & Nickel Alloys has selected the solution of hardening by solid solution. Inside this hardening mechanism, niobium and titanium are well-known to have the most efficient hardening effect without too much increase of the coefficient of thermal expansion.
So, even if the principal target for defining the new grade of filler metal was to obtain the required overmatching of mechanical properties, it was paid special attention to the other requirements of the cryogenic applications, which are basically those of Invar® M93 base material:

- the coefficient of thermal expansion of filler metal which must be as close as possible to that of base material. (CTE of welds made with Invar® M93 T = 2,8 10^{-6}/℃ between -185℃ and 20℃ in annealed conditions while CTE of Invar® M93 T wire is 4,0 10^{-6}/℃ and CTE of Invar® M93 base metal is 1,5 10^{-6}/℃). See **figure 2**.

- the absence of risk of reheating cracking in case of multi pass welding or cross bead welding. This property is achieved thanks to the mastering of the low level of impurities in the same way than Invar® M93 base metal.

- the absence of embrittlement and the stability of the austenitic structure for any considered temperature even after plastic deformation. This is also ensured by the perfect mastering of the chemical composition of iron nickel at the melting shop.

- the absence of loss of ductility and the maintaining of a high level of toughness at cryogenic temperature. See **table 1** and **figure 3**.

- the fatigue behaviour of the welds must be at the same level than the one of Invar® M93 base material. See **figure 4.**

Figure 1 gives comparative evolution of mechanical properties versus temperature for material taken from the Invar® M93 tube and for homogeneous weld when using Invar® M93 filler metal or Invar® M93 T filler metal.

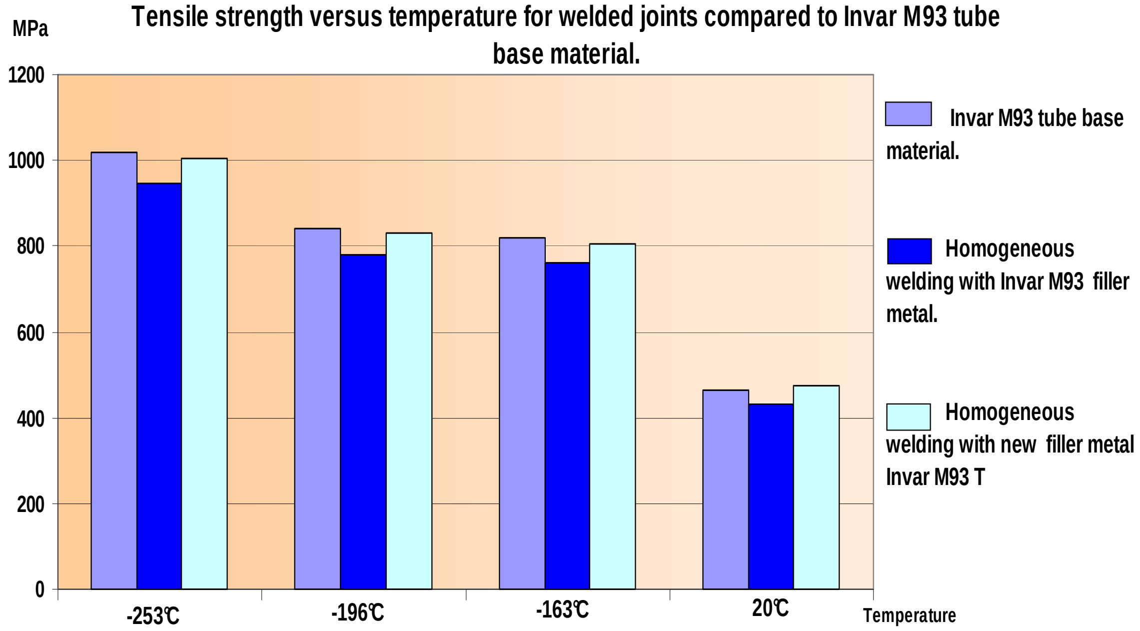


Figure 2: Comparative thermal expansion of Invar® M93 base metal, Invar® M93 T filler metal and the weld joint made with these two materials. We can see that the increase of CTE in the weld is very low, less than 1,2 10^{-6}/°C compared to the Invar ® M93 base material, so the local induced thermal stress is less than 25 MPa.

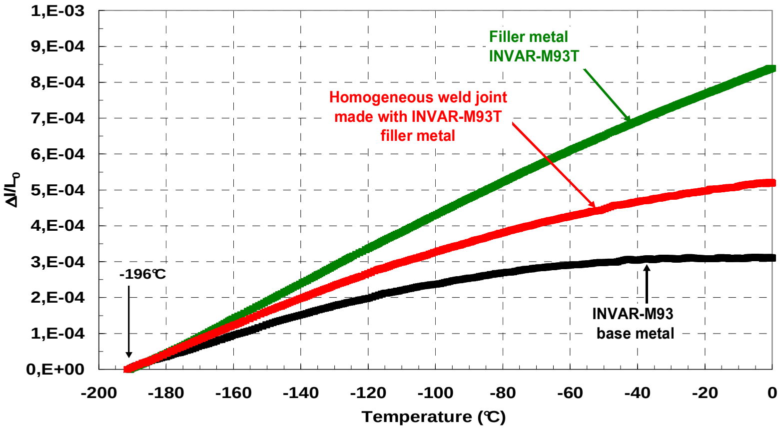
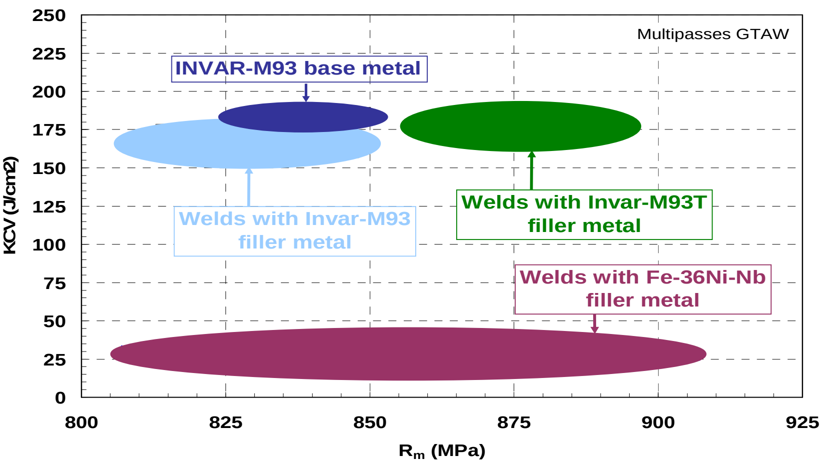


Table 1 gives some data on notch tests, bending tests and cross bend tests on welds made by GTAW in using the different filler metal solutions we have tested.
We can see that ductility of the welds remains very close to that of the base material either at room or at cryogenic temperature, when the filler metal is Invar® M93 T or Invar® M93.
Between the different grades tested, it is noteworthy that Invar® with added niobium shows particular brittleness at cryogenic temperature.

	Notch test at 20°C		Notch test at -196°C		Bending te st	Cross bead test
Filler metal grade	According to NF EN 100045-1, specimen with reduced section 5 x 10 mm (cut following weld axis)				Bending at 180°	Made on 3 mm thick material
	Energy (J/cm2)	Breaking	Energy (J/cm2)	Breaking	Cracks	Cracks
Invar® base metal	300	No	200	Yes	No	-
Invar® M93 D	149	No	122	Yes	No	No
Invar® M93 T	208	No	178	Yes	No	No
Invar® M93	188	No	165	Yes	No	No
Invar® with Nb added	85	Yes	31	Yes	No	No

Figure 3: Compromise between tensile strength and toughness at -196°C for welds made with Invar® M93 filler metal, Invar® M93 T filler metal and Invar® + Nb filler metal.



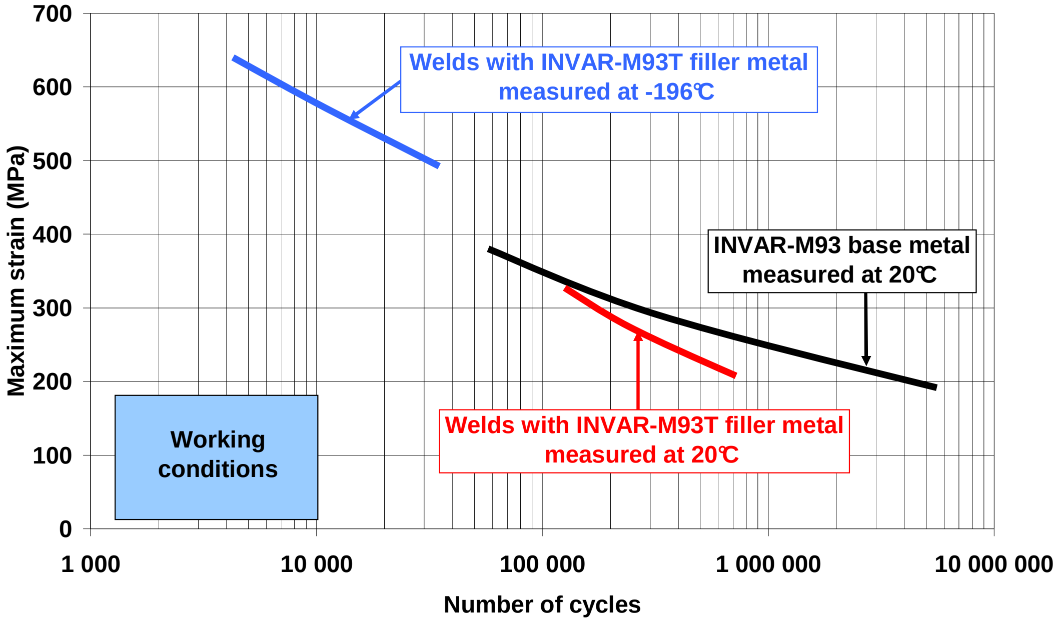


Figure 4 shows the fatigue behaviour of welded joints made with Invar® M93 T filler metal at room temperature and at cryogenic temperature compared to the one of Invar® M93 base metal. The fatigue properties are widely above the working conditions corresponding to the cyclic thermal stresses due to the loading and un-loading operations. The good behaviour of the welds made in using Invar® M93 T filler metal is also demonstrated by the fact that the break of specimens is always localised in the thermal affected zone.

In conclusion, within the different metallurgic solutions tested in order to reach the same level (or slightly higher) of mechanical properties than the one of Invar® M93 base metal, it appears that Invar® M93 T is the filler metal wire which gives the best compromise between all the required properties for the LNG transfer lines: welds with improved tensile strength and yield strength, very low increase of CTE, perfect weldability, high ductility and very good fatigue behaviour.

It is why ArcelorMittal – Stainless & Nickel Alloys provides now the new Invar® M93 T filler metal like it is the case for Invar® M93 filler metal in standard diameters both for MGAW and for GTAW processes. Please consult us.

INDUSTRIAL WELDING PROCESSES

The choice of welding process will be made in function of available equipments and environmental conditions at the tube manufacturer plant or on site. For instance, for the longitudinal welds and/or the circular welds, the choice will depend on the thickness of Invar® M93 base metal:

- thickness < 5 mm : PAW process with filler metal.
- thickness ≥5 mm : PAW process with filler metal + GTAW with filler metal.

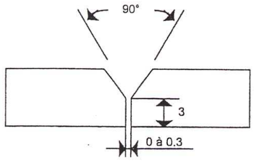
For the butt-welding between each tube, the automatic orbital welding can be done by GTAW or manual GTAW in case of difficulty of access or any other practical consideration; repairs can also be performed by multi-layer GTAW.

Whatever the welding process, in order to obtain the required mechanical and physical properties inside the welds, the most important point is to employ a dilution ratio of about 30% of the filler metal Invar® M93T in the fusion zone:

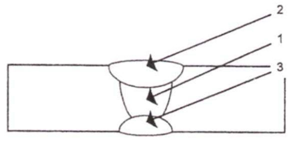
$$\text{Dilution ratio in fusion zone} = \frac{\text{Volume of filler metal}}{(\text{Volume of filler metal} + \text{Volume of base metal})} = 25\% \text{ to } 35\%$$

For that, an edge preparation is recommended as indicated in figure 1 but it is not absolutely necessary. It is always preferable to process to an inter-pass cleaning by grinding and brushing for removing any oxidation during the welding process.

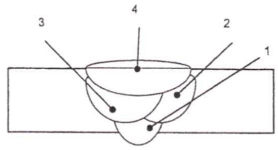
Edge preparation



Automatic :
PAW (1)
GTAW (2) and (3)



Manual :
GATW (1), (2), (3), (4)



For tube production in industrial quantities, studies have been made in order to optimize the welding parameters in such a way to obtain best performances under robust industrial and economical conditions. The welding parameters have been adjusted in such a way to master the shape and the grain size inside the weld, to minimize the thermal affected zone and then to keep at a high level the impact properties at room and cryogenic temperature through the management of the heat input during the welding operation.

The range of welding specifications for Invar® M93T is indicated in **table 2**.

Welding Procedure		**PAW Automatic**	**GTAW Automatic**	**GTAW Manual**
Base metal		**Invar® M93**		
Filler Metal		**Invar® M93T (ϕ = 1,2 mm)**		**Invar® M93T (ϕ = 1,2 mm)** (twist-joint)
Gas	**Plasma (l/mm)**	Ar + 2%H_2 (3 to 5)	-	-
	Annular (l/mm)	Ar + 5%H_2 (20 to 40)	- Ar + 30%H_e (15 to 40) - Ar + 5%H_2 (15 to 30)	Ar (10 to 20)
	Backing (l/mm)			
Electrical Characteristics	**Current (A) : DC (-)**	150 to 250	150 to 250	140
	Voltage (V)	25 to 30	10 to 20	14 to 16
	Heat input (kJ/cm)	9 to 23	4 to 15	10 to 20
Technique	**Initial and interpass cleaning**	Grinding - brushing		
	Travel speed (cm/mn)	20 to 25	20 to 25	7 to 10
	Filer metal speed	100 to 300	50 to 150	10 to 15

Please consult for details of Welding Procedure Specifications with all the welding parameters for different processes versus thickness.

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