INVAR® M93T

CONTROLLED EXPANSION ALLOY

Invar® M93T filler metal has been developed by Imphy Alloys in order to perform homogeneous welding of Invar® M93 tubes by PAW or GTAW. The chemical composition of the welding consumable has been optimized to fulfill requirements for pipe applications at cryogenic temperatures:

Mechanical properties

- Overmatching of welded joints.
- Toughness and no embrittlement at cryogenic temperatures.

Stability and CTE

- No martensitic transformation at cryogenic temperatures.
- Low coefficient of thermal expansion between LNG temperature and 0°C.

Weldability

- No solidification and reheat cracking during multi-layer welding or cross welding.
- No defects (porosity, micro crack).
- Repair welding capacity by manual GTAW.

I. FILLER METAL

The typical chemical composition of Invar® M93T filler metal is shown in table 1:

Typical values : Filler metal Invar® M93T							
Ni	**Ti**	**Mn**	**Si**	**C**	**S**	**P**	**Fe**
43	2.5	0.1	< 0.25	0.007	< 0.0015	< 0.0070	Balance

Table 1

II. WELDING PROCEDURE

The choice of welding process depends on the thickness of Invar® M93 base metal.

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

Repairs can be performed by multi-layer GTAW.

Whatever the welding process, the most important point is to employ a dilution ratio of about 30% of the filler metal Invar® M93T in the fusion zone:

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

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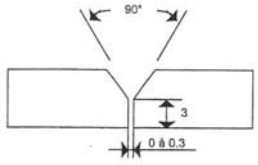
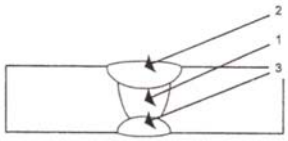
Edge preparation is recommended as indicated in figure 1 but is not necessary. Interpass cleaning by grinding and brushing is preferable to remove oxidation during the welding process.

Edge preparation



Automatic:

- PAW (1)
- GTAW (2) and (3)



Manual:

- GATW (1), (2), (3), (4)

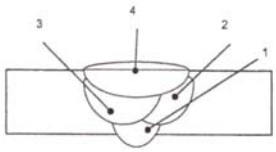


Figure 1

The range of welding specifications for Invar® M93T are 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/mn)	Ar + 2%H_2 (3 to 5)	-	-
	Annular (l/mn)	Ar + 5%H_2 (20 to 40)	- Ar + 30%He (15 to 40) - Ar + 5%H2 (15 to 30)	Ar (10 to 20)
	Backing (l/mn)	Ar (20 to 40)	-	-
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
	Filler metal speed (cm/mn)	100 to 300	50 to 150	10 to 15

Table 2

III. MACROSTRUCTURES AND CHEMICAL COMPOSITION

The mechanical properties, stability, CTE, and weldability are the results of the specific chemical composition of welded joints (see table 3). More precisely:

- **Overmatching** and **low CTE** are the result of a compromise in titanium content. Addition of titanium improves mechanical properties of the fusion zone, by strain hardening, but impairs CTE. Figure 2a and 2b show that the micro-hardness is higher in the fusion zone than in the base metal. Optimum titanium content of the welded joint is roughly 1%.

- **Stability** with respect to martensitic transformation is improved by the high mean nickel content of the fusion zone (37% to 41%).
- **Weldability** is closely related to the low sulfur content of both filler metal and base metal.

Typical values : Welded joint							
Ni	**Ti**	**Mn**	**Si**	**C**	**S**	**P**	**Fe**
37 to 41	0.75 to 1.25	< 0.4	< 0.25	< 0.04	< 0.0015	< 0.0070	Balance

Table 3: Chemical composition of welded joints obtained by automatic PAW + GTAW or manual GTAW.

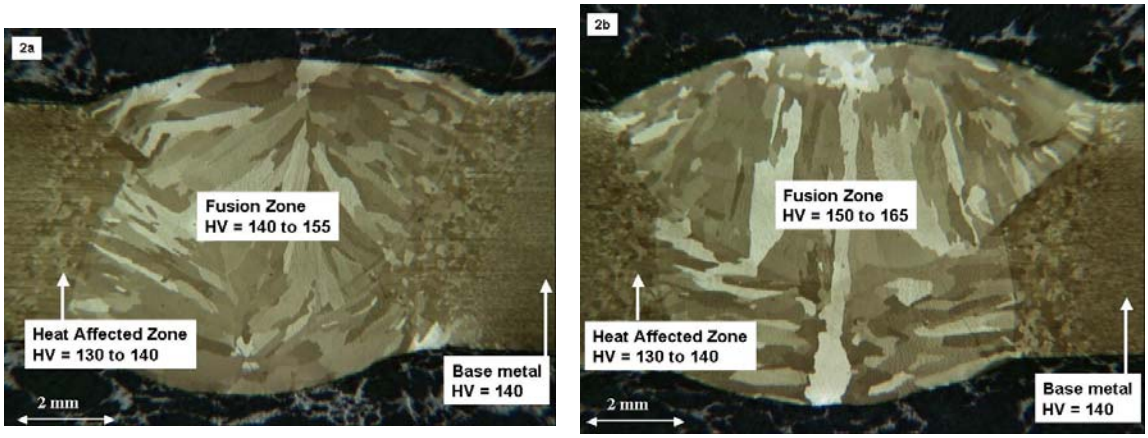


Figure 2: Cross section of welded joints performed in industrial condition. (a) automatic PAW + GTAW. (b) Manual GTAW. The micro-hardness of the fusion zone is higher than that of the base metal.

IV. MECHANICAL PROPERTIES

The filler metal Invar® M93T gives rise to excellent mechanical properties either in case of automatic welding or manual (repair welding). Table 4 indicates high UTS and toughness at cryogenic temperatures:

Base metal = Invar® M93 Filler metal = Invar® M93T		0.2 YS (MPa)	UTS (MPa)	KCV (J/cm²)	Face-Bend Root-Bend
Automatic PAW + GTAW	25°C	270	475	235	No defect
	-196°C	620	815	160	-
Manual GTAW	25°C	290	486	210	No defect
	-196°C	670	805	150	-

Table 4

V. COEFFICIENT OF THERMAL EXPANSION

Expansion tests performed at low temperatures give information on stability with respect to martensitic transformation. As shown on figure 3, the welded joint obtained with Invar® M93T filler metal is quite stable down to –196°C.

Moreover, the CTE between –163°C to 0°C of welded joints is less than 2.9 10^{-6}/°C meanwhile the CTE of Invar® M93 base metal is 1.4 10^{-6}/°C. So, The difference in CTE is of about 1.5 10^{-6}/°C.

As a conclusion, assuming an elastic modulus of the welded joint in the range of 155 000 MPa, the maximum thermal stress can be estimated to: $\sigma = E \times \Delta\alpha \times \Delta T \sim 38$ Mpa << 0.2%YS

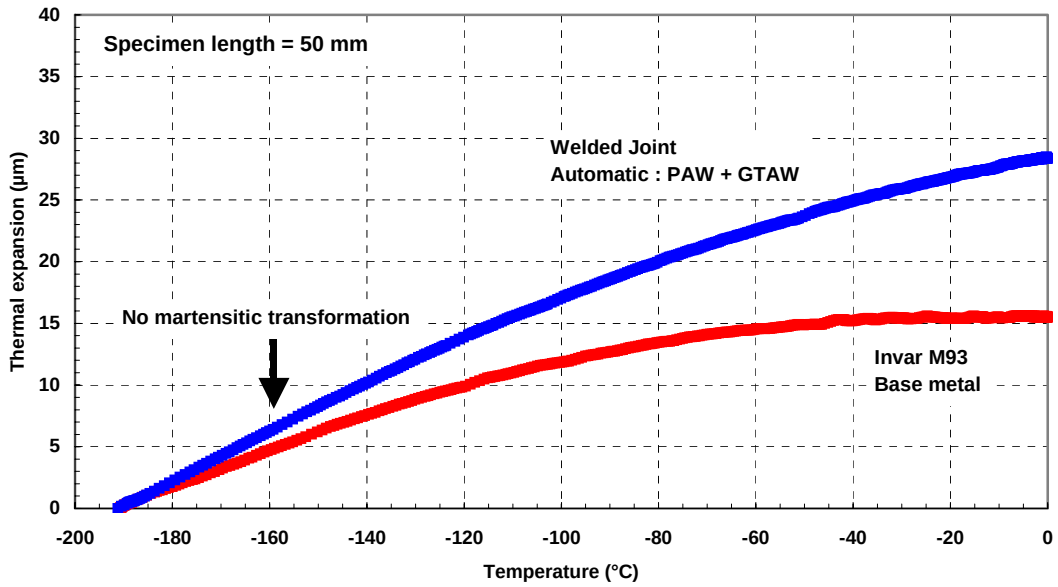


Figure 3

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