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# An Experimental Study of Inconel 625 Weld Cladding Technology for Corrosion and Erosion Wear Protection in Petroleum Application

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## Abstract

*Drilling and production petroleum equipment like valves and blowout preventers (BOP) must be designed to resist to very high pressures and to present a very good corrosion resistance in petroleum environments. An economical solution to manufacture petroleum components which combine the requirements of high strength and corrosion resistance is weld cladding with a corrosion resistant alloy. Cladding with nickel-chromium alloys such as Inconel 625 offer high strength and a very good corrosion resistance in petroleum environment, together with a good weldability to steel. Pulsed plasma arc deposition, gas metal pulsed arc welding technology, thermal spaying and laser deposition were successfully used as metal surface coating techniques with Inconel 625 for specific application.*

*In this paper single layer and two layers of Inconel 625 wire deposition is studied by using Metal Inert Gas Pulsed – Arc welding technology. The objectives of the study are to optimize the process parameters for cladding a low alloy steel in order to obtain minimum dilution ratio, good surface finish and porosity control. The cladded material fulfills the dilution and workability requirements imposed by standards and design only after cladding two successive layers.*

**Key words:** *weld cladding, Metal Inert Gas Pulsed – Arc, corrosion protection.*

## Introduction

Drilling and production petroleum equipment like valves and blowout preventers (BOP)must be designed to resist to very high pressures and to present a very good corrosion resistance in petroleum environments.

An economical solution to manufacture petroleum components which combine the requirements of high strength and corrosion resistance is weld cladding with a corrosion resistant alloy. Cladding with nickel -chromium alloys such as Inconel 625 offer high strength and a very good corrosion resistance in petroleum environment, together with a good weldability to the steel.

Pulsed plasma arc deposition, gas metal pulsed arc welding technology, thermal spaying and laser deposition were successfully used as metal surface coating techniques with Inconel 625 for specific application.

In this paper single layer and two layers of Inconel 625 wire deposition is studied by using Metal Inert Gas Pulsed –Arc welding technology. The objectives of the study are to optimize the process parameters for cladding a low alloy steel in order to obtain minimum dilution ratio, good surface finish and porosity control

## Experimental Procedure

One and two layers of Inconel 625 were cladded onto two steel plates in vertical position by using Metal Inert Gas Pulse Arc welding technology.

The cladding wire used in the study was Inconel 625, - NIBAS 70/207, with 1.2 mm diameter, a product of Bohler Co. Table 1 presents the chemical composition of the cladding wire [wt%].

**Table 1.** Chemical composition of the cladding wire

| C% | Si% | Mn% | P% | S% | Cr% | Ni% | Cu% | Ti% | Nb% | Fe% |
|---|---|---|---|---|---|---|---|---|---|---|
| <0.01 | <0.1 | 3.2 | 0.002 | 0.001 | 20.4 | 72.9 | <0.1 | 0.3 | 2.5 | 0.3 |

Mechanical specifications of the product NIBAS 70/20 FD are presented in Table 2.

**Table 2.** Mechanical specifications of the cladding wire

| Yield strength $R_{p0.2}$ [MPa] [20ºC] | Tensile strength $R_m$ [MPa] [20ºC] | Elongation *A* % [20ºC] | Charpy energy *KV* [J] |
|---|---|---|---|
| ≥ 380 | ≥ 620 | ≥ 35 | ≥ 90 |

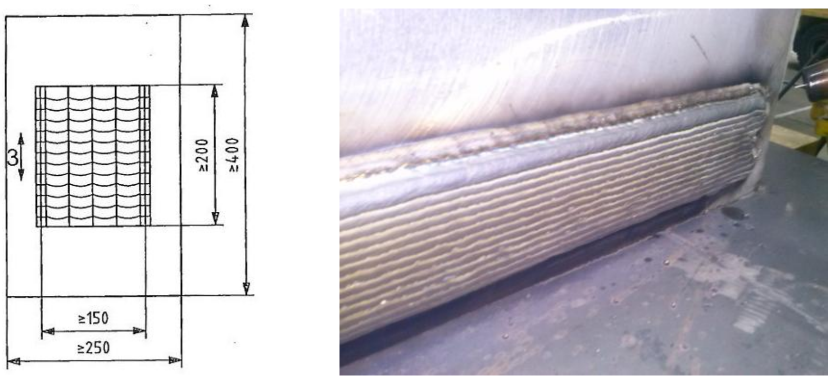
As base material has been used a low alloy steel type A215/WCB/WCC with the chemical composition presented in Table 3.

**Table 3.** Chemical composition of the base metal wt%

| Fe% | C% | Si% | Mn% | P% | S% | Cr% | Mo% | Ni% | Cu% | Al% |
|---|---|---|---|---|---|---|---|---|---|---|
| 97.8 | 0.1361 | 0.3881 | 0.6175 | 0.0143 | 0.0228 | 0.2206 | 0.0677 | 0.2017 | 0.240 | 0.050 |

For the purpose of this experiment two steel plates have been used, with the geometry presented in figure 1:

- Sample no. 1 – one layer weld surfaced;
- Sample no. 2 – two layers weld surfaced.




**a.** **b**.

**Fig. 1.** Plate for experimental study of cladding technology:
a) plate geometry; b) as deposited Inconel 625 overlay

The welding equipment used consists of:

- Welding device ESAB, multiprocess ARISTOMIG 500;
- Welding head, MIG automatic with double cooling (in the body of the welding head and in the gas nozzle) product of ABICOR BINZEL ZMA 500;
- ROHNA torch for preheating;
- Welding robot MOTOMAN;
- Infrared thermometer FLUK 62.

The Inconel 625 wire was deposited performing the following process parameters:

1. Preparing the welding surface by mechanical processing.
2. Establishing the welding parameters by successive testing on a similar, proofing material, until the following parameters were obtained (which established the metallic bond with the base material):
   - Maximum amperage: 190-217 A;
   - Minimum amperage: 120 A;
   - Average voltage of the electric arc: 23,7 V;
   - Wire feed rate : 7,8 m/min;
   - Welding rate: 42 cm/min;
   - Free length of the wire between the piece and the streak nozzle: 12 mm;
   - Diameter of the streak nozzle: 1,4 mm;
   - Protective gas: Argon 98% + $O_2$ 2%;
   - Protective gas flow : 18 l/m.
3. Preheating the base material.
   The preheating was performed with ROHNA torch, until reaching the temperature of 50 ºC, confirmed by measurements with infrared thermometer FLUK 62.
4. Weld cladding with INCONEL 625 of the base material, using Pulsed Arc MIG procedure.
   The cladding was performed in seven adjacent rows, partial superposed. The distance center-to-center of the welding's was 5 mm, as shown in figure 1b.
   After the weld cladding, the samples were cooled in normal environmental conditions.
   During the welding the piece temperature was between 80 ºC and 90ºC.
   After welding , samples have been extracted and evaluated by optical microscopy , scanning election microscopy , hardness measurements ,bending test and iron concentration (ferrite contend in overlay).

## Results and Discussions

As shown in figure 2 on a specimen extracted perpendicular to the welding direction, the base material microstructure is ferrite and pearlite, specific to low alloy steel and the cladding layer consists of columnar dendrites grown perpendicular to the fusion line, as a typical structure of a Ni-Cr alloy.

The chemical composition for one layer overlay, determined with the scanning electron microscope is presented in Table 4.

**Table 4.** Chemical composition of the first deposited layer

| Measurement No. | Ni% | Cr% | Fe% | Nb% | Mn% | Ti% | Si% |
|---|---|---|---|---|---|---|---|
| 1 | 57.6 | 16.4 | 9.6 | 3.9 | 3.4 | 0.5 | 0.2 |
| 2 | 60.5 | 17.8 | 11.5 | 1.2 | 2.6 | 0.3 | 0.1 |
| 3 | 59.0 | 15.9 | 9.3 | 0.6 | 4.9 | 0.6 | 0.3 |

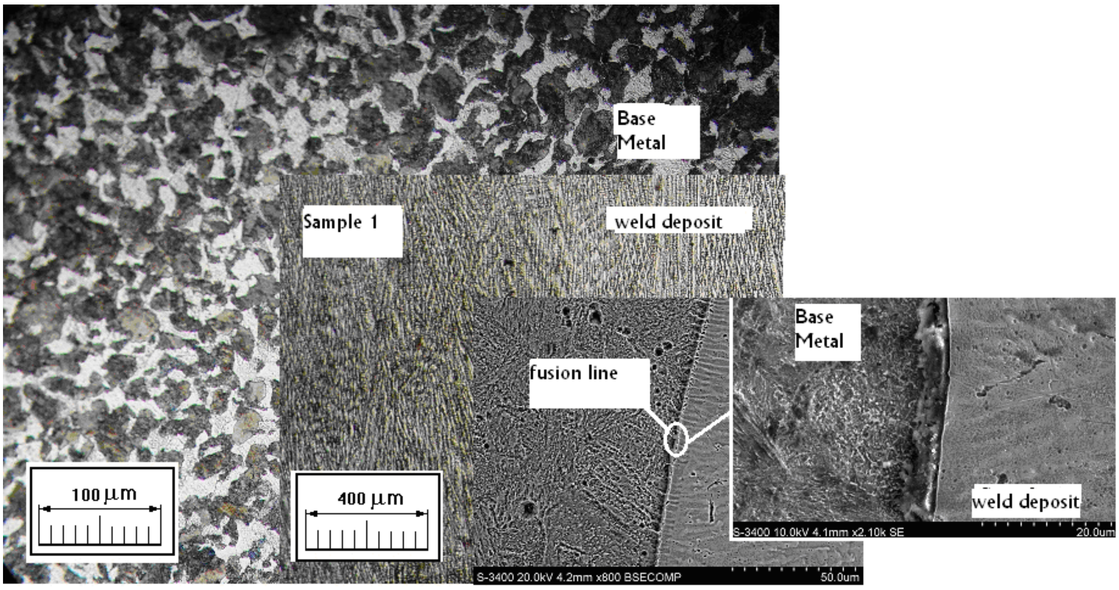



**Fig. 2.** Etched optical micrograph of cross sections for one layer deposit of Inconel 625

Ferrite content was determined by using Digital Ferrite Meter and the results obtained are presented in Table 5.

**Table 5.** Ferrite content of the first deposited layer

| Measurement No. | Ferrite Number | Ferrite content % |
|---|---|---|
| 1 | 2.3 | 1.61 |
| 2 | 2.7 | 1.89 |
| 3 | 2.4 | 1.68 |

As can be seen in Tables 4 and 5 ,the iron contend ant the ferrite contend levels are higher than the values accepted for ensuring corrosion resistance in petroleum environments.

The hardness of the cladded layers for all samples was measured a micro-hardnessmeter tipe Duroscan 20 ,according with standard SR EN ISO 6507-1/2006.

The results for one layer deposition are presented in table 6 and in figure 3.

**Table 6.** Hardness results for one layer deposition

| Measured zone | Results [HV1] |
|---|---|
| Base material | 249, 246 |
| HAZ | 272, 429, 399, 206 |
| Cladded material | 212, 208, 201, 195 |

The hardness values indicate that Inconel 625 is satisfactory weldable to low alloy base metal. The hardness of Inconel 625 weld overlay is smaller than the hardness of the base metal.

The bending test was performed on specimens having 10 mm thickness cut from the plate specimens in the longitudinal welding direction. The static bending test parameters according with standard SR EN ISO 5173/2010 are presented in Table 7 and figure 4.

After bending, the convex surface visually examined shows no evidence of cracking in the weld deposit or in heat affected zone.

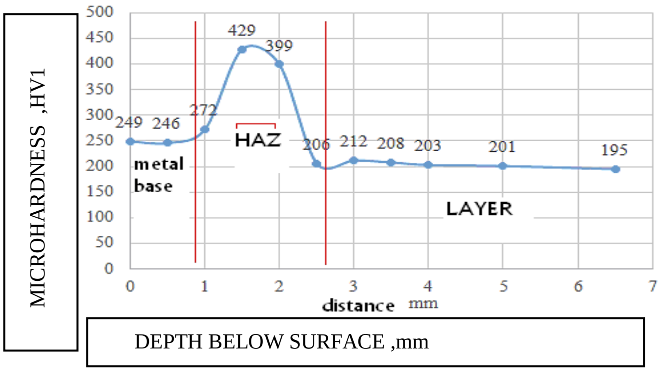



**Fig. 3.** Hardness versus depth

**Table 7.** Static bending test parameters and results

| Material | Specimen thickness | Mandrell diameter | Rollers diameter | Distance between rollers | Bending angle | Obs. |
|---|---|---|---|---|---|---|
| Sample 1 | 10 mm | 40 mm | 40 mm | 65 mm | 180º | No imperfections in cladding layer |

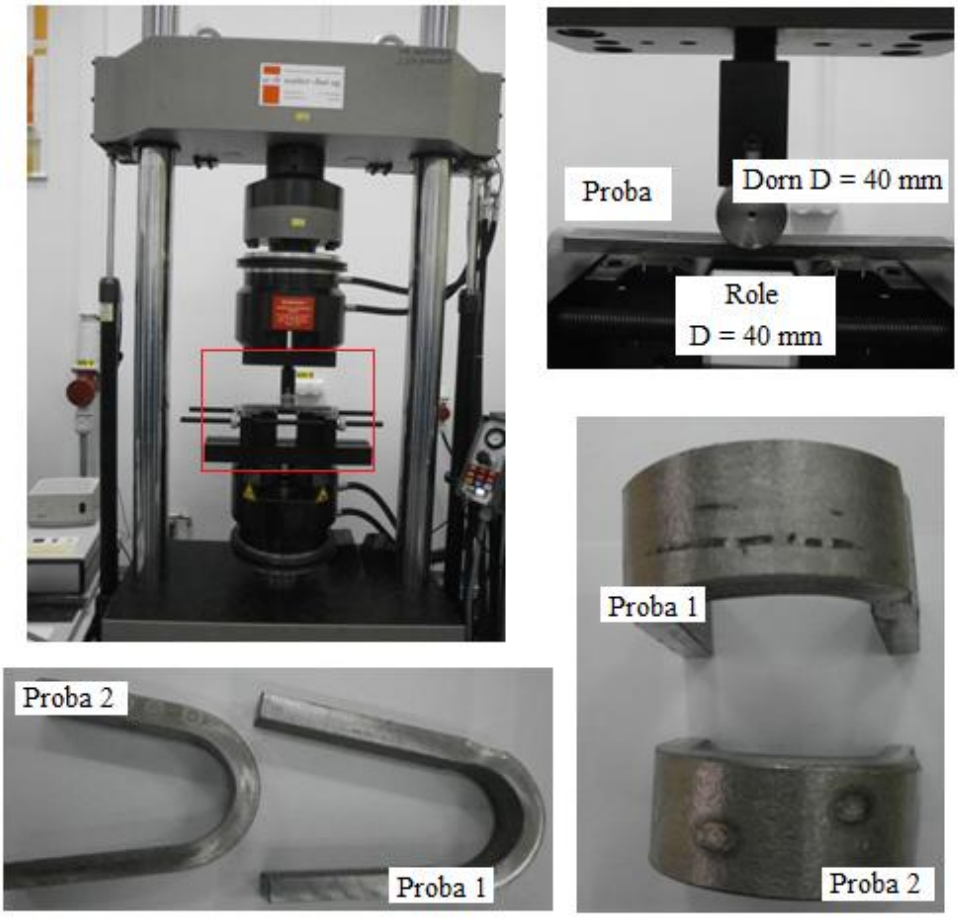



**Fig. 4.** Bending test

In order to reduce the iron contend in the Inconel 625 overlay, two layers were welded onto the steel plates. The first and the second layer were welded using the same optimized process parameters.

Figure 5 shows the optical micrograph of cross section for the two layer deposit of Inconel 625.

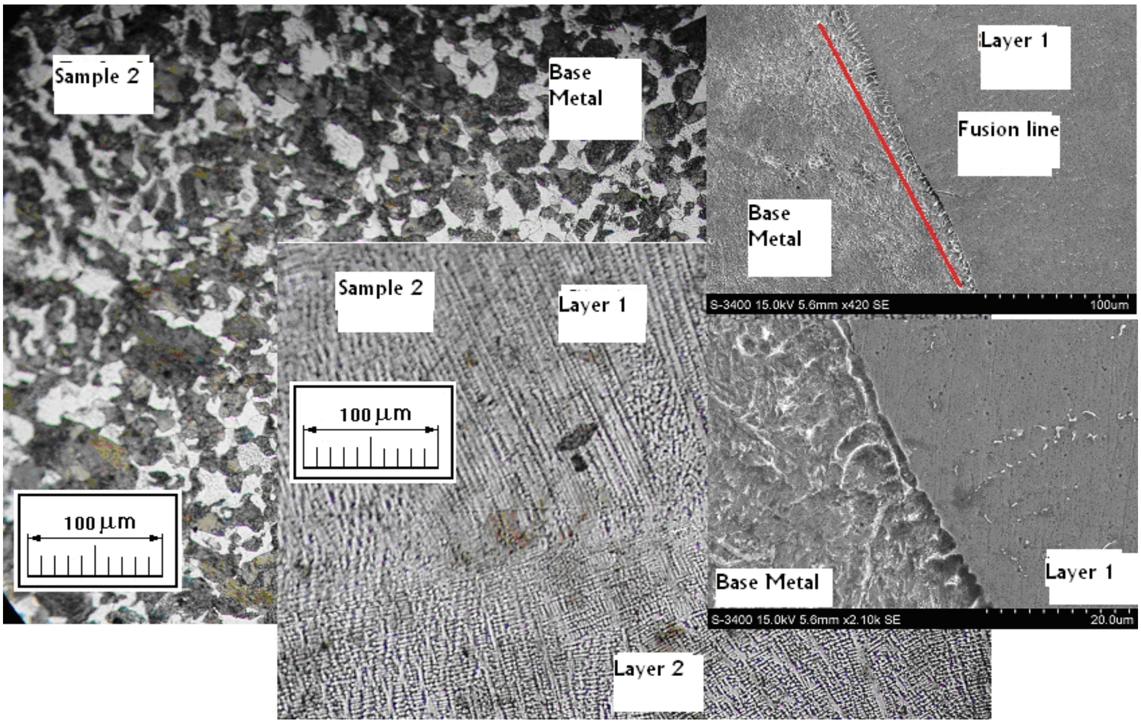



**Fig. 5.** Etched optical micrograph of cross section of two layers deposit of Inconel 625

The transition from the initial layer of weld metal to the second layer consists of columnar dendrites which are continuous through the layers.

The chemical composition of the second layer is presented in Table 8.

**Table 8.** Chemical composition of the Inconel 625 layers

| No. | Layer | Ni | Cr | Fe | Nb | Mn | Ti | Si |
|---|---|---|---|---|---|---|---|---|
| 1 | Layer 1 | 67.9 | 19.1 | 2.6 | 3.3 | 3.4 | 0.3 | - |
| 2 | | 69.1 | 19.7 | 2.8 | 2.8 | 3.2 | 0.3 | - |
| 3 | | 67.9 | 19.7 | 3.0 | 2.8 | 3.2 | 0.3 | - |
| Average | | 68.3 | 19.5 | 2.8 | 3.0 | 3.3 | 0.3 | |
| 1 | Layer 2 | 73.5 | 17.7 | - | 1.6 | 2.8 | - | - |
| 2 | | 70.4 | 16.6 | - | 3.6 | 3.6 | - | - |
| 3 | | 72.7 | 17.8 | - | 1.5 | 2.5 | - | - |
| Average | | 72.2 | 17.4 | - | 2.2 | 3.0 | - | - |

It is observed that the level of iron content decreased in the second layer to an acceptable value ,and the chemical composition is similar to that of the wire electrode .Also the ferrite content in the second layer decreased to very low values , as presented in Table 9.

The hardness of the two layer deposit is presented in Table 10 and in figure 6.

The hardness values of both layers are the same .The hardness values of the base metal and of the heat affected zone are favorable reduced due to the heating produced by the second layer.

**Table 9.** Ferrite content

| No. | Layer | F.N. | Ferrite content [%] |
|---|---|---|---|
| 1 | Layer 1 | 2.7 | 1.89 |
| 2 | | 2.7 | 1.89 |
| 3 | | 2.8 | 1.96 |
| 1 | Layer 2 | 0.3 | 0.21 |
| 2 | | 0.3 | 0.21 |
| 3 | | 0.4 | 0.21 |

**Table 10.** Hardness variation for two layers deposition

| Measured zone | Results obtained through HV1 measurements |
|---|---|
| Base material | 184 – 183 – 197 |
| HAZ | 218 – 249 – 212 |
| Layer 1 | 202 – 216 – 200 |
| Layer 2 | 213 – 205 – 212 – 216 |

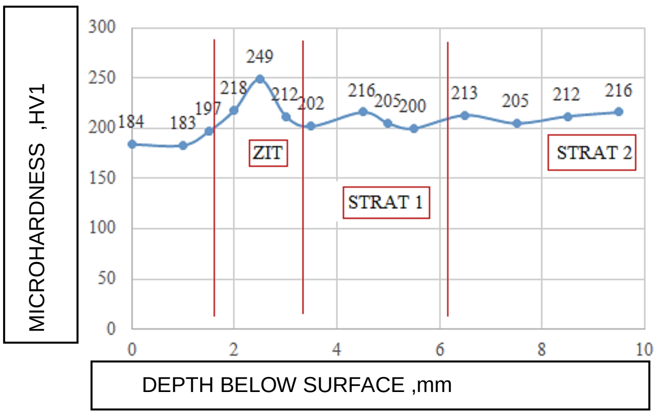



**Fig. 6.** The hardness versus depth

The bending test performed on specimens with two layers Inconel 625 overlay shows no evidence of cracking in the weld deposit , heat affected zone or base metal after bending to 180 deg.

## Conclusions

- In this research the deposition process parameters for Inconel 625 onto a low alloy steel by using Metal Inert Gas Pulsed –Arc welding technology were studied.
- The cladded material fulfills the dilution and workability requirements imposed by standards and design only after cladding two successive layers.
- The two layers deposition process reduces favorable the hardness of the base metal and of the heat affected zone.

## Acknowledgements

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## References

1. Abioye, T.E., Folks, J., Clare, A.T. – A parametric study of Inconel 625 wire laser deposition, *Journal of Materials Processing Technology*, 213, 2013, pp. 2145-2151.
2. Hasson, D.F., Zaris, C., Apriggliano, L., Fraser, C. – Surfacing of 3.25% Nickel Steel with Inconel 625 by the Gas Metal Arc Welding – Pulsed Arc Process, *Welding Research Supplement to the Welding Journal*, Jan. 1978, pp. 1-8.
3. Menter, P. – *Alloy 625 Weld Overlaid Carbon Steel Casings for high pressure Seawater and Produced Water Applications. Case Study*, www.sulzerpumps.com
4. Carvalho, C.S. et al. – New insight on the solidification path of an alloy 625 weld overlay, *Journal of Materials Research and Technology*, **2**(3), 2013, pp. 228 -237.
5. * * * – *Inconel alloy 625. Special Metals Composition*, Aug. 2013, www.specialmetals.com
6. Fujia, X., Yaohiu, L., Yuxin, L., Binshi, X., Peng, H. – Effect of Heat Treatment on microstructure and chemical proprieties of Inconel 625 alloy fabricated by pulsed plasma arc deposition, *Physics procedia*, **50**, 2013, pp. 48-54.

# Cercetări experimentale privind tehnologia de încărcare cu Inconel 625 pentru protecţia echipamentelor petroliere împotriva uzurii şi coroziunii

## Rezumat

*Echipamentele petroliere de tipul robinetelor şi prevenitoarelor de erupţie se proiectează astfel încât să asigure rezistenţa mecanică şi la coroziune. O soluţie economică o reprezintă placarea suprafeţelor supuse coroziunii şi eroziunii cu material rezistente la acţiunea mediilor agresive. În prezenta lucrare se cercetează tehnologia de încărcare cu Inconel 625 utilizând procedeul de sudare Metal Inert Gas Pulsed-Arc. Rezultale obţinute în urma analizelor metalografice, de duritate, a probei de îndoire şi determinarea cantităţii de ferită în stratul depus confirmă posibilitatea aplicării acestei tehnologii la nivel industrial.*