Chapter 19
Weld Bead Geometry of Ni-Based Alloy Deposited by PTA Process for Pipe Conduction of Shale Gas

C. Echavarria-Figueroa, F. García-Vázquez, J. Ruiz-Mondragón, H.M. Hernández-García, D. González-González, and A. Vargas

Abstract The transportation of shale gas has the problem that the piping used for the extraction does not resist the erosion generated by the amount of solids causing cracks over the surface and it is necessary to extend the life of the pipelines. Plasma transferred arc (PTA) welded coatings are used to improve the surface properties of mechanical parts. Therefore, in this paper is studied the use of Ni-based filler metal as weld bead deposits on A36 steel substrates by PTA. In order to determine the suitable conditions to ensure coating quality on the substrate a design of experiments (DOE) was determined. Welding current, feed rate, and travel speed were used as input parameters and the dilution percentage as the response variable. The composition and properties of hardfacing or overlay deposited are strongly influenced by the dilution obtained. Control of dilution is important, where typically low dilution is desirable. When the dilution is low, the final deposit composition will be closer to that of the filler metal, and the wear and corrosion resistance of the hardfacing will also be maintained. To evaluate the features on the weld beads/substrate interface a microstructural characterization was performed by using scanning electron microscopy and to evaluate the mechanical properties was carried out hardness test.

Keywords Plasma transferred arc (PTA) • Weld bead geometry • Ni-based alloy • A36 steel • Dilution

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19.1 Introduction

The decrease of non-renewable resources has brought the need to explore other unconventional energy sources as the shale gas. This activity has promoted an important development in technology acquisition, recovery, and transportation of this resource. The transportation is the most critical aspect, because the amount of solids generates erosion, in addition, the mechanisms of corrosion by hydrogen embrittlement causing cracks on the pipes. In order to minimize these problems nickel-based materials and stainless steels are commonly used; however, its cost is very high. Alternatively it proposed a coating over the cracks to extend the lifetime of the pipelines. Previously, conventional welding processes were used with the purpose of making coatings on mechanical components to increase the properties and extend the life of the material.

In recent years, overlays deposited by PTA or hardfacing have an extensive use in applications such as valve industries, hydraulic machineries, mining industries, and coatings [1]. PTA process employs the plasma principle hence it may be considered an evolution of GTAW process, where the high-energy concentration is due to the use of a constrictor nose, which restrains the column diameter of an electric arc established between a tungsten electrode and the workpiece in an inert gas atmosphere, usually argon. Feeding material is carried to the plasma jet by a gas stream, which might be inert, active, or a mixture of active and inert gases. A third gas flow is employed to protect the metal pool from atmospheric contamination. Even though there is the possibility of using mixtures of active and inert gases, argon is typically employed for all three-gas systems [2, 3].

This process stands out for its high quality, metallurgically bonded with substrate and low diluted overlays. These overlays also exhibit high homogeneity, low oxide content, and low concentrations of other unwanted inclusions [4]. The composition and properties of hardfacing or overlay deposited are strongly influenced by the dilution obtained. Control of dilution is important, where typically low dilution is desirable. When the dilution is low, the final deposit composition will be closer to that of the filler metal, and the wear and corrosion resistance of the hardfacing will also be maintained [5].

To provide a coating with higher wear resistance is chosen N-625 filler metal based on its properties (hardness, wear, and corrosion resistance). Through a design of experiments (DOE) they are looking to get proper values to make coatings of N-625 filler metal with low dilution rate values sought to be less than 5 % in order to increase the mechanical properties on A36 base metal.

19.2 Experimental Procedure

In this work, automatic PTA hardfacing was carried out for depositing Ni-based filler metal alloy over A36 steel plates approximately of size 15 × 8 × 1.5 cm. Chemical composition (wt.%) of the N-635 filler metal is shown in Table 19.1. Microstructural characterization of the overlays was performed by using a JEOL scanning electron microscope equipped with EDS semiquantitative analysis using an accelerating voltage of 25 kV, spot size of 4.7, and a working distance of 6.5 mm. The controllable process parameters identified based on their significant effect on weld bead geometry were welding current, feed rate, and welding speed with values showed in Table 19.2 and constant parameters in Table 19.3. On the other hand, dilution was evaluated as the area ratio between the substrate melted area and total melted area as indicated in Fig. 19.1.

Table 19.1 Chemical composition (wt.%) of the N-625 filler metal

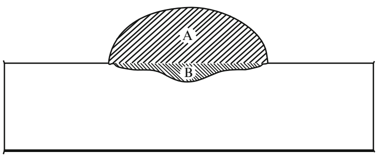
Cr	C	Mo	Nb	Fe	Ni
21	0.05	9.2	3.5	3	Balance

Table 19.2 Processing PTA parameters

Variable parameters	Factor levels		
	−1	0	1
Feed rate (gr/min)	20	26	32
Welding speed (cm/min)	15	17	19
Welding current (A)	140	160	180

Table 19.3 Processing PTA constant parameters

Constant parameters	
Plasma gas (l/min)	5
Shield gas (l/min)	12
Powder gas (l/min)	5



$$\delta = \frac{\text{Substrate melted area}}{\text{Total melted area}} \times 100 = \frac{B}{A + B}$$

Fig. 19.1 Procedure used to evaluate dilution levels

Table 19.4 Parameters used in the design of matrix of experiments

Piece	Feed rate (gr/min)	Welding speed (cm/min)	Welding current (A)	Dilution (%)
1	1	1	1	4.67
2	1	1	−1	0.27
3	1	−1	−1	3.19
4	1	1	1	12.17
5	−1	−1	1	25.84
6	−1	−1	−1	1.24
7	−1	1	−1	1.79
8	−1	1	1	17.35
9	0	0	0	5.38
10	0	0	0	6.22
11	0	0	0	5.74
12	0	0	0	5.12

The chosen matrix design (Table 19.4) to conduct the experiment was a 2^3 design with central points. It consists of 12 steps of coded conditions and comprising a half replication of $2^3 = 8$ factorial design with four central points [6]. In the matrix DOE welding parameters at the middle level (0) constitute center points whereas the combination of each welding parameter at its lower value (−1) or higher value (1). Thus these 12 experimental runs allow observe the effect of welding parameters over the percentage of dilution.

19.3 Results and Discussion

Dilution is a determining factor whenever one wants to assess coating properties. Compared to other welding processes PTA requires less quantity of material to be deposited with improved metallurgical properties and allows precise metering of metallic powder feedstocks [7, 8]. The shape of the weld bead geometry is affected by the values of PTA process parameters kept during deposition [9, 10]. Dilution results measured by stereoscopy for the different processing conditions are shown in Fig. 19.2.

Based on the best dilution level the sample 6 (Fig. 19.2c) was selected because it presented suitable weld bead geometry; although there are samples with a smaller dilution, but these do not have the appropriate geometry and properties for an expected overlay. The microstructure of sample 6 shown in Fig. 19.3a shows the interface zone without chemical attack, Fig. 19.3b is the zone between interface-HAZ-base metal and Fig. 19.3c shows the microstructure of interface zone with chemical attack using optical microscopy.

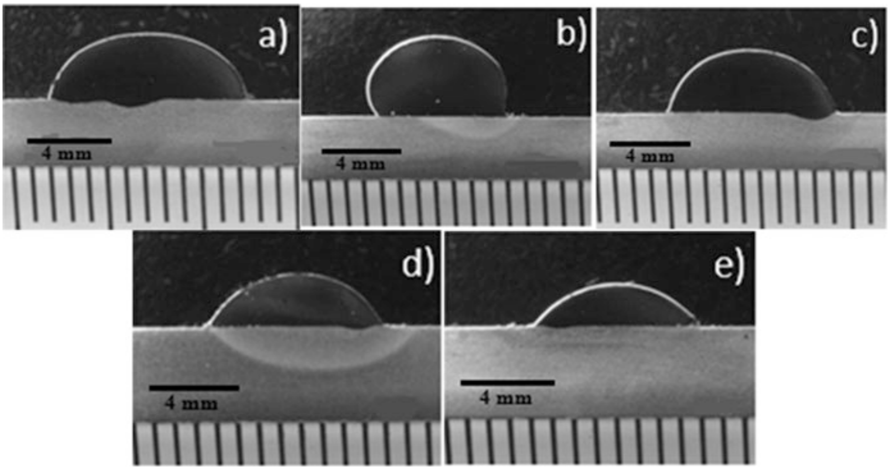


Fig. 19.2 Evaluation of dilution by stereoscopy (**a**) P1, (**b**), P2, (**c**) P3, (**d**) P6, (**e**) P7

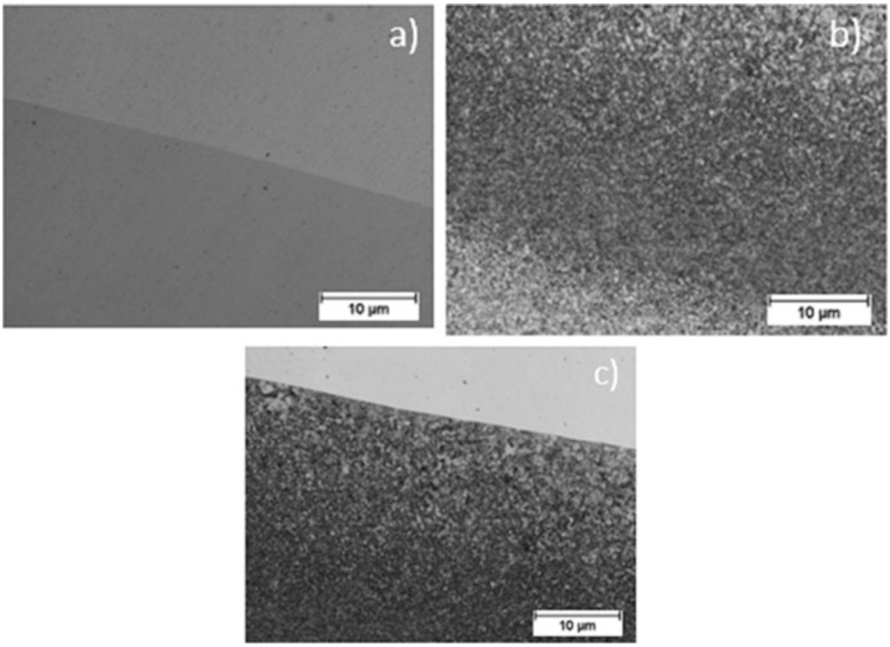


Fig. 19.3 Microstructure of piece 6 using optical microscopy, (**a**) interface zone without attack, (**b**) zone between interface-HAZ-base metal, and (**c**) interface zone

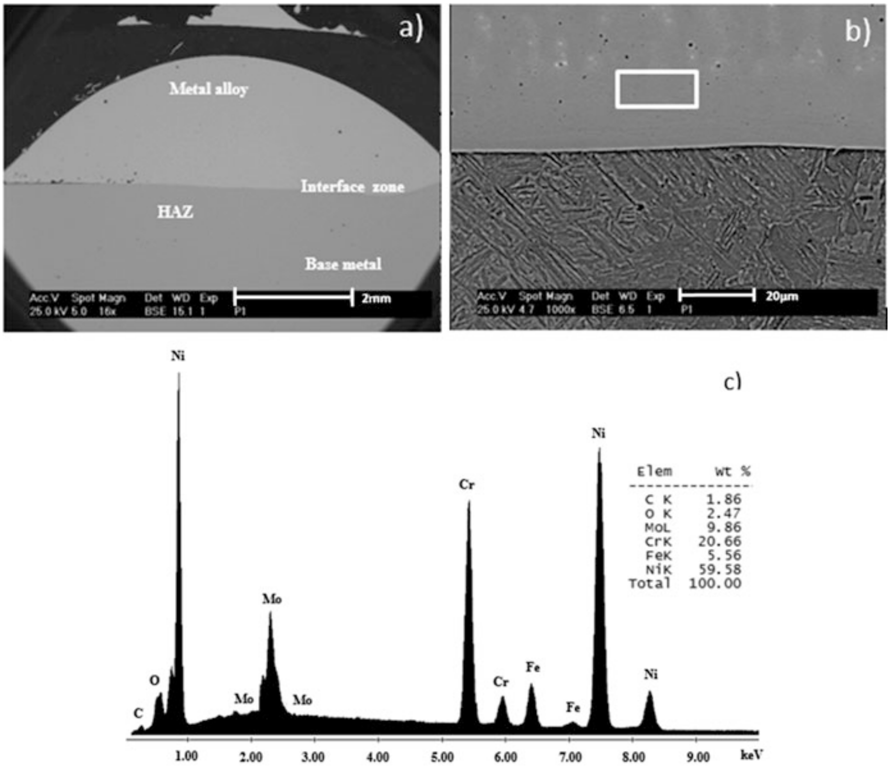


Fig. 19.4 (**a**) Back scattered electron image of the cross section of the weld bead, (**b**) microstructure of the weld bead and zone for EDS spectrum analysis, and (**c**) EDS spectrum of the overlay (metal alloy)

Figure 19.4a shows a back scattered electron image of the cross section microstructure of the weld bead or overlay deposited by PTA process. As it can be observed the microstructure consists of the weld bead (nickel base alloy), interface zone, the heat affected zone (HAZ), and a base metal [11]. Figure 19.4b shows a microstructure of base metal and the rectangle specifies an amplified zone for a sample of base metal selected to examine by EDS. The EDS spectrum corresponding to base metal presents high content of Ni and Cr, Fig. 19.4c. The deposits obtained using a low feed rate, welding current, and speed parameters of plasma transferred arc process exhibit a low percentage of dilution and good geometry on the weld bead.

The results of the hardness test of the samples with Ni base filler metal are shown in Fig. 19.5a, the microstructure in Fig. 19.5b illustrates the zones where hardness was measured. The hardness traverse of sample 6 presents a homogeneous progress, thus again it is checked that the sample 6 shows the best combination of parameters, specifically the parameters with low values. The sample 6 does not

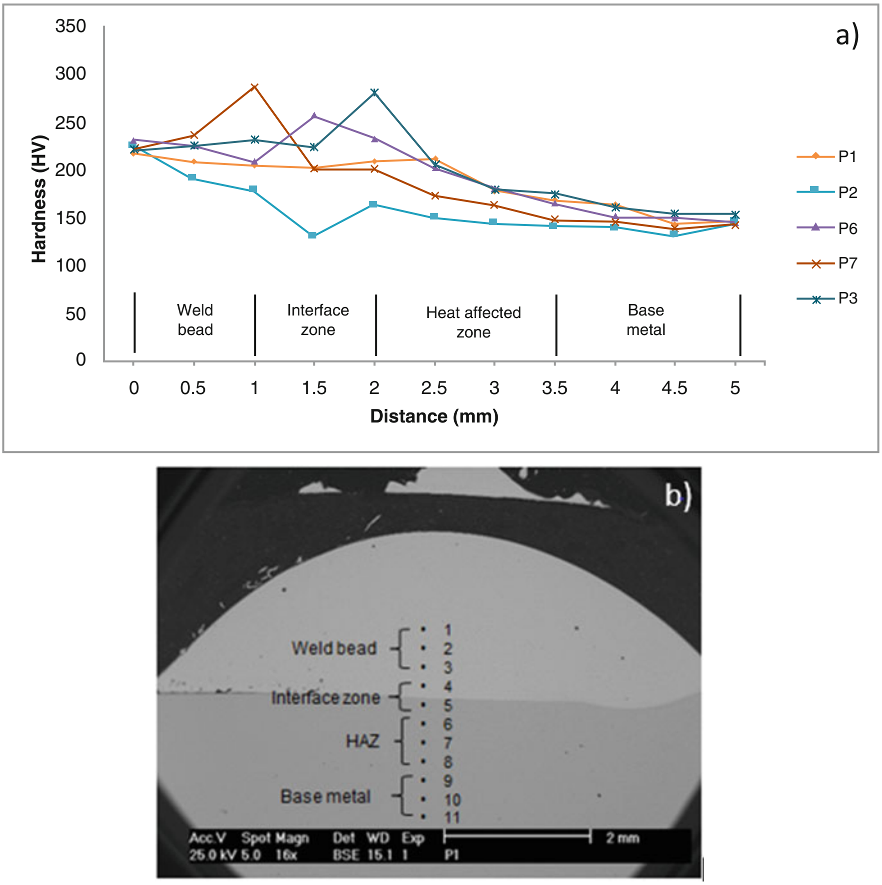


Fig. 19.5 (**a**) Hardness profiles for coatings using Ni base filler metal on A36 steel and (**b**) microstructure illustrating the indentation zones performed in the sample

present significant changes in hardness profile obtained but hardness of base metal increases by coating performed and provides longer life to the material.

In comparison with results obtained by Siva et al. [12], the plots of main effects for dilution showed in Fig. 19.6a obtained by DOE, showed a similar behavior in relation at welding current range. When the current welding are low, there is a decrease of the percentage of dilution, as is shown in Fig. 19.6b. This is attributed to the fact that the heat input to the base metal increases when this parameter is increased. Dilution percentage decreases steadily with increase in welding speed (S). This is attributed to the reduced heat input per unit length of weld bead when S is increased (Fig. 19.6c) [13, 14].

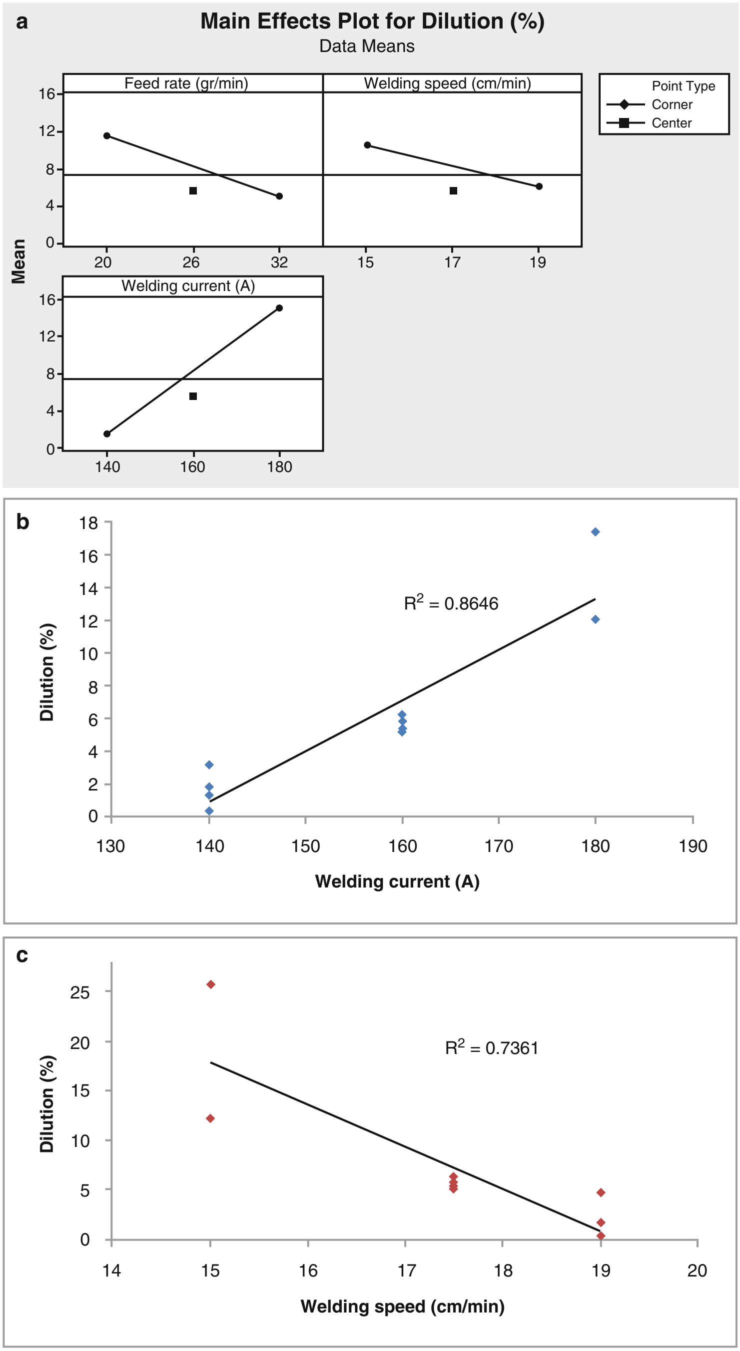


Fig. 19.6 (**a**) Main effects plot for dilution (**b**) Welding current effect over dilution (**c**) Welding speed effect over dilution

19.4 Conclusions

Dilution percent increases with an increase in welding current as a result of the heat input.

Dilution percent decreases with an increase in welding speed.

According to results obtained from design of experiments (DOE) it is suggested that feed rate has not relationship with the parameters of welding speed and welding current but it's necessary the control of this parameter.

The N-625 filler metal can be used like a coating over the pipes to bring more lifetime, such a result can be measured by the profile hardness.

The optimal conditions to obtain a good coating in order of low dilution percent are: welding speed (19 cm/min), welding current (140 A), and feed rate (20 gr/min).

The combination of parameters with lower values enables a dilution less than 5 %.

References

1. Balamurugan S, Murugan N (2013) Simulation of plasma transferred arc (PTA) hardfaced on structural steel with titanium carbide. J Eng Comput Appl Sci 2:10–14
2. Davis JR (1993) Hardfacing, weld cladding and dissimilar metal joining. In: ASM handbook-welding, brazing and soldering, 10th edn. ASM, Metals Park
3. Lucas W (1990) TIG and PLASMA welding, Abington Publishing, Cambridge
4. Gruzdys E, Meskinis S (2011) Influence of plasma transferred arc process parameters on structure and mechanical properties of wear resistive NiCrBSi-WC/Co coatings. Mater Sci 17:140–144
5. Kumar S, Mondal DP, Khaira HK (1999) Improvement in high stress abrasive wear property of steel by hardfacing. J Mater Eng Perform 8:711–715
6. Silva Prasad K, Srinivasa Ch, Nageswara D (2011) Prediction of weld bead geometry in plasma arc welding using factorial design approach. J Miner Mater Charact Eng 10:875–886
7. Eschnauer H (1980) Hard material powders and hard alloy powders for plasma surface coating. Thin Solid Films 73:1–17
8. Das CR, Albert SK, Bhaduri AK, Kempulraj G (2003) A novel procedure for fabrication of wear-resistant bushes for high-temperature application. J Mater Process Technol 141:60–66
9. Gunaraj V, Murugan N (1999) Prediction and comparison of the area of the heat-affected zone for the bead-on-plate and bead-on-joint in submerged arc welding of pipes. J Mater Process Technol 95:246–261
10. Kou S (2002) Welding metallurgy, 2nd edn. Wiley, Hoboken
11. Vergara V, Dutra J, Climaco S (2011) Hardfacing by plasma transferred arc process. InTech, Croatia
12. Siva K, Murugan N, Raghupathy VP (2009) Modeling, analysis and optimization of weld bead parameters of nickel based overlay deposited by plasma transferred arc surfacing. Int Sci J 1:174–182
13. Balasubramian V, Babu S, Lakashminarayanan AK (2008) Understanding the parameters controlling plasma transferred arc hardfacing using response surface methodology. Mater Manuf Process 23:674–682 (Taylor and Francis group)
14. Wilden J, Bergmann JP, Frank H (2006) Plasma transferred arc welding modeling and experimental optimization. J Therm Spray Technol 15(4):779–784 (ASM International)