Effect of Heat Input on Micro-Hardness and Shear Strength of Inconel 625 Hardfacing onto AISI 347 Steel pipes by GMAW Process

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Abstract. Inconel 625 is one of the most accepted hardfacing material having good corrosion resistance properties at high temperature applications. Hardfacing is the deposition of a hard surface layer to the base metal by means of welding. The benefit of hardfacing is resistance to environmental stresses mainly corrosion at elevated temperatures. Thermal input plays a critical role for manufacturing good hardfaced components with respect to weld bead geometry, cooling rate, etc. In the present study, an L9 orthogonal array of input parameters were carried out with different heat input combinations using 98% Argon + 2% CO₂ as shielding gas. Single layer hardfacing was done. The bead-on-pipe welding trials and macroscopic analysis were carried out to find the optimal welding parameters that yielded minimum dilution. The hardfaced layer thickness varies from 1.88mm to 2.58mm on substrate following optimum welding parameters. Visual inspection results reveal that most of welds of higher heat input conditions possess good quality. It is visually observed that width of weld increases with increase in welding heat input. It is noticed that in the range of 200-250 mm/min welding speed and 150A of welding current, good reinforcement and weld bead width at optimum penetration is observed in the experiments. Shear strength test and micro-hardness test were performed over test samples prepared from hardfaced part. Results revealed that both micro-hardness and shear strength of the hardfaced layer were more than that of base metal and values of both increased with increase in heat input. The Inconel 625 hardfaced layer exhibited 32 % higher hardness than the substrate material AISI 347.

1. Introduction
Hardfacing has become a major breakthrough for issues associated to applications for wear-resistant components, as it can increase the service life of engineered components. Hardfacing makes a new layer on the top surface of substrate with different compositions in which the deposited layer is harder than that of base material. Compared to other surfacing techniques, hardfacing has some distinctive advantages, such as enhancement of hardness and wear resistance of job surfaces, providing good bonding and favourable microstructure of hardfaced part. Hardfacing by welding has generally been used to improve the wear resistance in the agricultural, sugar, excavating and other industries to increase the hardness and wear properties of mechanical components [1]. Hardfacing is a method commonly used to treat surfaces subject to heavy wear and corrosion and for the manufacture of new components, their repair and their useful life for the most varied industries [2]. Various welding methods, such as metal inert gas welding (MIG), submerged arc welding (SAW), oxyacetylene gas welding (OAW) and
shielded metal arc welding (SMAW) are widely used for depositing hard layers. The main difference between these methods are efficiency of the welding process, higher rate of deposition, dilution percentage on the substrate or base material and the filler material cost for laying hard deposits. The GMAW process is generally used to overhaul surfaces by hard surfacing as a result of its easy application, ability to weld at high densities of current and its potential to deposit hard layers of multiple filler material, specifically in repairing damaged parts of greater importance to the industries [3]. The demand of a joining process depends mostly on the operational considerations of the thermal distribution in the hard deposit which is beneficial for estimating the changes in metallurgical aspect and their effect on the mechanical integrity [4].

The selection of welding filler material and a welding process are first carried out in making the deposits by hardfacing [5]. Gopa et al. [6] investigated the percentage of dilution in the substrate by the hard deposit which alters the microstructure and their effect on hardness wear resistance of the hardfaced deposit. The microstructures and wear properties of the deposited layers of nickel-based hardfacings provide better abrasion wear resistance [7]. The studies on the single layer clad beads of Inconel 625 by SMAW produced low dilution and at lower current of 80A and wear resistance was enhanced under identical conditions of wear test [8]. The experimentation by Kotecki and Ogborn [9] shows that the most significant factor for wear resistance was the microstructure. The studies by John J. Coronado et al [1] states that the higher level of dilution by joining process reduced the wear characteristics of single layer hardfaced deposits and an increase in abrasion resistance was seen with multiple hardfacing layers applied one above other. Kesavan et al. [10] observed the metallurgical changes and wear performance of Colmonoy 5 hardfaced coating at high temperatures and noticed a decrease in wear loss and COF-coefficient of friction with increase in test temperatures. The investigations by Jin-Kim et al. [11] on nickel based (Deloro 50) deposits by hardfacing revealed higher wear loss at room temperature and suggested nickel based hard deposits for high temperature nuclear power plant applications with oxidative wear. In the present investigation, Inconel 625 filler wire is hardfaced on AISI 347 by GMAW process applying as shielding gas. Process parameters such as welding current and welding speed were selected in 98% Argon + 2% CO2 three levels, keeping welding voltage constant so that nine different heat input had been produced and nine weld bead samples were produced. Analyzing the weld bead geometry of the samples, 3 best samples with reference to bead geometry were selected and the corresponding process parameters were identified. Macro hardness testing and shear testing of hardfaced layer were carried out to check the effect of thermal input on mechanical behaviour of hardfaced layer.

2. Materials and Systems

The chemical composition of base metal and filler wire, i.e. AISI 347 austenitic stainless steel and ERNiCrMo-3 are shown in Table 1, and Table 2 respectively. ERNiCrMo-3 filler wire diameter is 1.2 mm. OTC DaIhen FD-B6 model robotic MIG/MAG welding machine using DC source, with rotary positioner is shown in Fig. 1.

Fig. 1. Robotic welding setup for hardfacing
Table 1. Chemical composition of Base material (AISI 347 pipe)

| Name of the element | C   | Mn  | Si  | P   | S   | Cr | Mo | Ni  | N   | Fe  |
|---------------------|-----|-----|-----|-----|-----|----|----|-----|-----|-----|
| Composition in %    | 0.03| 2.00| 0.75| 0.45| 0.03| 18.00| 3.00| 14.00| 0.10| Balance |

Table 2. Chemical composition of filler material (ERNiCrMo-3)

| Name of the element | Cr   | Co | Si | Mn | Fe | Mo | Nb | Other | Ni |
|---------------------|------|----|----|----|----|----|-----|--------|----|
| Composition in %    | 21.00| 0.90| 0.40| 0.40| 5.00| 9.00| 3.50| 0.90   | Balance |

3. 3. Experimental Procedure

3.1. Bead on plate experiments

Inconel 625 weld beads were hardfaced on AISI 347 base metal by GMAW process using 98% Argon + 2% CO2 as shielding gas. Welding Current and welding speed were taken in three levels such as 130 A, 140A, 150A and 200mm/min, 225mm/min, 250mm/min respectively so that nine number of samples were formed.

3.3.3 Macrograph of hardfaced sample in longitudinal direction

Table 3. Heat input and input parameters for bead-on-plate trials

| Sample No. | Welding Current, I (A) | Voltage, V (Volts) | Welding speed, S (mm/min) | Heat input (kJ/mm) |
|------------|-------------------------|---------------------|----------------------------|-------------------|
| 1          | 130                     | 14.9                | 200                        | 0.46              |
| 2          | 130                     | 14.9                | 225                        | 0.41              |
| 3          | 130                     | 14.9                | 250                        | 0.37              |
| 4          | 140                     | 15.7                | 200                        | 0.53              |
| 5          | 140                     | 15.7                | 225                        | 0.47              |
| 6          | 140                     | 15.7                | 250                        | 0.42              |
| 7          | 150                     | 16.5                | 200                        | 0.59              |
| 8          | 150                     | 16.5                | 225                        | 0.53              |
| 9          | 150                     | 16.5                | 250                        | 0.48              |

Welding voltage was kept constant during the experiment. The whole experiments were replicated twice. Equation (1) is used to find heat input, Q.

\[ Q = \frac{V \times I \times 60}{S \times 1000} \times \eta \]  \hspace{1cm} (1)

Where Q = Heat Input (kJ/mm), V = Voltage (V), I = Current (A), S = Welding Speed (mm/min) and \( \eta \) = Efficiency (In this experiment, it is taken as 0.8).

The heat input and other process parameters are shown in Table 3. The samples were cut in transverse direction by wire EDM using 0.18mm molybdenum wire, ground and etched with 2% nital solution and checked under Streuss weld expert. Weld bead geometry components like top reinforcement, bead width and depth of penetration were measured with the help weld expert microscope.
3.2. Hardfacing experiments
Single layer Inconel 625 hard deposits were performed on AISI 347 by GMAW process using 98% Argon + 2% CO2 as shielding gas. Three sets of heat inputs along with process parameters such as welding current and torch travel speed were selected on the basis of better results of weld bead geometry formation in previous experiments.

3.3. Micro-Vicker’s hardness test
Micro-Vicker’s hardness tests for the samples made were carried out by Matsuzawa MMT-X Vickers hardness tester by calculating the depth of penetration of the indenter into the specimen under fixed test conditions.

3.4. Shear test of hardfaced part
Shear strength of hardfaced sample is measured by a shear testing device. Shear strength is calculated by following formulae.

\[
\text{Shear strength} = \frac{\text{Shear load}}{\text{Area}}
\]  

(2)

4. Results and Discussion
4.1. Results of bead-on-plate trials
Visual inspection results reveal that most of welds of higher heat input conditions possess good quality. It is visually observed that width of weld increases with welding heat input as expected. In all cases continuity in weld deposition is found. Spatters are varied from high range to low range with different heat input conditions. High spatter at lower current indicates the possibility of globular mode of metal transfer.

4.2. Weld bead characteristics of bead-on-plate trials
Table 4 shows the results of various weld bead geometry of bead-on-plate trials using 98% Argon + 2% CO2 as shielding gas. The observations from bead-on-plate trials clearly specifies that at higher input condition weld bead width, reinforcement and depth of penetration increases with increasing heat input. It is noticed that within the range of 200-250 mm/min welding speed and 150A of welding current, good reinforcement and weld bead width at optimum penetration is observed in both sets of experiments. Three heat input conditions (0.59 kJ/mm, 0.53 kJ/mm, and 0.48 kJ/mm) are selected for hardfacing based on visual inspection, weld bead geometry and their effects by thermal input from bead on plate trials.

![Fig. 3. Weld bead characteristics measured from macrographs](image)

4.3. Micro-Vicker’s hardness test
The three zones, on which the values were measured are the base metal, the deposited weld zone and the heat effected zone. Average hardness value of base material AISI 347 is 188 HV. Table 5 shows hardness values of three zones. From the result it is observed that hardness value is decreasing from hardfaced zone (237-255) to base metal (185-192). Hardness of the interface zone is 210-233. Fig.3 shows graphical representation of hardness at different zone.
Table 4. Measured values from macrographs of bead-on-plate trials

| Sample No. | Welding Current, I (A) | Voltage, V (Volts) | Welding speed, S (mm/min) | Heat input (kJ/mm) | Top reinforcement (mm) | Weld bead width (mm) | Depth of penetration (mm) |
|------------|------------------------|-------------------|--------------------------|-------------------|----------------------|---------------------|-------------------------|
| 1          | 130                    | 14.9              | 200                      | 0.46              | 2.21                 | 3.51                | 1.92                    |
| 2          | 130                    | 14.9              | 225                      | 0.41              | 2.04                 | 3.59                | 1.97                    |
| 3          | 130                    | 14.9              | 250                      | 0.37              | 1.88                 | 3.64                | 2.06                    |
| 4          | 140                    | 15.7              | 200                      | 0.53              | 2.43                 | 4.09                | 2.05                    |
| 5          | 140                    | 15.7              | 225                      | 0.47              | 2.29                 | 4.15                | 2.12                    |
| 6          | 140                    | 15.7              | 250                      | 0.42              | 2.17                 | 4.28                | 2.19                    |
| 7          | 150                    | 16.5              | 200                      | 0.59              | 2.76                 | 4.57                | 2.18                    |
| 8          | 150                    | 16.5              | 225                      | 0.53              | 2.58                 | 4.72                | 2.35                    |
| 9          | 150                    | 16.5              | 250                      | 0.48              | 2.49                 | 4.98                | 2.59                    |

Fig. 4. Hardness at different zones of hardfaced part.

Fig. 5. Bar chart for heat input vs Shear stress of hardfaced samples

Table 5. Hardness values of bead on plate experimentations

| Sample No. | Heat input (kJ/mm) | Hardness value on base metal (HV) | Hardness value on weld bead zone (HV) | Hardness value on the interface zone (HV) |
|------------|--------------------|-----------------------------------|--------------------------------------|------------------------------------------|
| 1          | 0.46               | 189                               | 245                                  | 218                                      |
| 2          | 0.41               | 192                               | 249                                  | 214                                      |
| 3          | 0.37               | 188                               | 237                                  | 210                                      |
| 4          | 0.53               | 189                               | 251                                  | 227                                      |
| 5          | 0.47               | 187                               | 247                                  | 221                                      |
| 6          | 0.42               | 190                               | 248                                  | 215                                      |
| 7          | 0.59               | 187                               | 255                                  | 233                                      |
| 8          | 0.53               | 185                               | 250                                  | 226                                      |
| 9          | 0.48               | 189                               | 246                                  | 223                                      |

4.4. Shear test

Table 6 shows the results of shear stress test on hardfaced samples. Shear strength of hardfaced samples are greater than base metal as standard ultimate shear strength of AISI 347 austenitic stainless steel at annealed condition is given by 430-460 MPa.
Table 6. Shear strength values of hardfaced layer

| Sample No. | Heat Input (kJ/mm) | Shear area (mm²) | Shear force (kN) | Shear stress (kN/mm²) |
|------------|-------------------|------------------|------------------|-----------------------|
| 1          | 0.59              | 45.43            | 21.94            | 0.483                 |
| 2          | 0.53              | 38.06            | 17.96            | 0.472                 |
| 3          | 0.48              | 33.92            | 15.87            | 0.468                 |

Fig. 5 shows graphical representation of shear strength against heat input, which shows shear strength increases with increase in heat input within experimental domain. From the chart it is obtained that shear strength increases with increase of heat input. From the observations, it is seen that in all the specimens, shear occurs at the heat affected zone or at the base metal. In no case, shear occurs at weld bead. Inconel 625 filler wire contains alloying elements like Cr, Ni, Mo, Si, Mn, which are responsible to increase hardness and shear strength. The austenitic phase present in AISI 347 converts into retained austenite on cooling which has more mechanical strength than base metal.

5. Conclusion
From the results obtained from various tests performed it is observed from visual inspection that welds with higher input are found to be of good quality and high depth of penetration than lower heat input. The hardness of Inconel 625 hardfaced portion is found to be significantly higher than AISI 347 steel base pipe, as it has the presence of hardening elements like chromium, nickel, molybdenum, etc. Results of shear test clearly indicate that shear strength increases with increasing heat input. Shear strength of all the hardfaced samples is better than base metal. Comparing both sets of shear stress test, maximum shear stress is obtained in the present investigation at 0.59 kJ/mm heat input with 150A welding current, 16.5V weld voltage and 200 mm/min weld torch travel speed.

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