Characterisation of microstructure, mechanical and corrosion properties of pulsed MIG welded modified P91 steel weld metal

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Abstract: Varying the shielding gas composition with argon and carbon dioxide influences the properties of the weldments which are evaluated using microstructural, micro-hardness and corrosion studies. The modified P91 steel samples are welded by Pulsed Metal Inert Gas welding process with different shielding gas mixture, i.e., 95%Ar-5%CO₂, 80%Ar-20%CO₂ and 60%Ar-40%CO₂. The welded steels are studied metallographically by observing microstructures at three different regions namely at the base metal, Heat Affected Zone (HAZ) and the Weld zone. Hardness measurements are also done using Vicker’s micro-hardness tester. Corrosion studies in acidic media (sulphuric and nitric acid media of four different normalities 0.5, 1.0, 1.5 and 2.0) are done in the welded region and the parent metal to compare the corrosion resistance. Of all the welded samples, welds made with the shielding gas composition of 95%Ar-5%CO₂ exhibits good corrosion resistance over the other two welds while the weld made with the shielding gas composition of 60%Ar-40%, shows very poor corrosion resistance.

1. Introduction
To reduce the environmental pollution from fossil fuels used in power generating plant, plants should run at high temperature and pressure. It calls for a material having improved temperature properties. Among the existing Cr-Mo ferritic steels, modified 9%Cr-1%Mo (P91) steel developed by the Oak Ridge National Laboratory in USA by adding the small amount of Vanadium and Niobium is being used worldwide today for high temperature application. These added Nb and V forms fine carbo nitrides [1,2] and strengthens the material by preventing the movement of subgrain boundaries, by impeding knitting reactions between free dislocations and subgrain boundaries by pinning sub boundary dislocation.

Application of P91 steel necessitates welding that affects the micro structures, mechanical and corrosion properties [3-7] of the metal. Arivazhagan et al [3] studied the influence of weld metal composition on mechanical and micro structure properties of welded metal and found that the presence of Nb & V greatly affects the toughness of the material. Effect of shielding gas composition on mechanical properties of welded modified P91 steel was studied by Kamaraj et al [4] and found that increasing of purity of argon content reduces inclusion percentage and increases toughness of the weld metal. During welding, alloying elements present in the electrode favors retaining of δ ferrite and greatly influences mechanical properties [5]. Even welding process has significant effect on mechanical properties and investigated by Magudeeswaran et al [6]. Murugan et al [7] used pulsed Metal Inert Gas welding process.
and found that it improves stable spray mode metal transfer, high deposition rate and produces refined structure due to pulsed current.

The present study deals with the effect of shielding gas composition on corrosion behavior of pulsed MIG welded modified 9%Cr-1%Mo steel and along with microstructure and micro hardness distribution studies were carried out.

2. Experimental

Modified 9Cr-1Mo steel (P91) plates were normalized at 1040 °C for 1 hour and tempered at 760 °C for 1 hour. This heat treated base metals were cut into the size of 200*60*12 mm and preheated to the temperature of 200°C, subsequently joined by single “V” groove butt joint in flat (1G) position (with included angle of 60° and the root gap of 1.5 mm) using Pulsed MIG Welding process Table 1 and 2 shows the composition of the base metal and filler metal respectively and welding parameters are shown in the table 3. Welding was performed using 1.2 mm diameter electrode of 9% Cr-1% Mo steel and with varying shielding gas composition of CO2 and Argon mixture. Three different shielding gas compositions were used namely 95%Ar-5%CO2, 80%Ar-20%CO2 and 60%Ar-40%CO2. After completion of welding, post weld heat treatment is done by heating to 760°C for an hour and then cooled down to 400°C in a controlled manner and followed by air cooling.

Microstructural characterization was carried out by Optical Microscope using the etchant called Viella’s reagent (1 g picric acid, 5 ml HCl and 90 ml distilled water). Micro hardness distribution across the parent metal, heat affected zone and weld metal was determined by Vicker’s micro hardness tester (MATSUZAWA-MMW-X3) with the application of 500 g of load for 15 s. The corrosion studies were conducted (Potensiosstat/ Galvanostat, CH instruments, USA) using Tafel extrapolation method in two different acids (Sulphuric and Nitric acid) and at four different concentrations (0.5 N,1 N,1.5 N and 2 N).

| Table 1: Composition of the base metal. |
|----------------------------------------|
| Elements | C | Mn | Si | Cr | Mo | V | Nb | Ni | Fe |
| Wt. %    | 0.08 | 0.39 | 0.50 | 9.4 | 1.0 | 0.25 | 0.09 | 0.13 | Bal. |

| Table 2: Composition of the filler metal. |
|------------------------------------------|
| Elements | C | Mn | Si | Cr | Mo | V | Nb | Ni | Fe |
| Wt. %    | 0.1 | 0.5 | 0.3 | 9.0 | 1.0 | 0.2 | 0.06 | 0.7 | Bal. |

| Table 3: Welding Parameters. |
|------------------------------|
| Parameter                   | 95%Ar-5%CO2 | 80%Ar-20%CO2 | 60%Ar-40%CO2 |
| Voltage(v)                  | 17.3         | 17.3          | 17.3          |
| Current(amp)                | 72           | 72            | 72            |
| Wire feeding rate(m/min)    | 1.8          | 1.8           | 1.8           |
| Welding speed(mm/sec)       | 5.06         | 5.14          | 5.03          |
| Pulsed current(amp)         | 125          | 125           | 125           |
| Background current(amp)     | 18           | 18            | 18            |
3. Results and discussion

3.1 Microstructure
Microstructure of base metal, heat affected zone and weld metal captured using optical microscope are shown at Magnification of 100X in Figure 1a-g.

Figure 1: a) Micro structure of the base metal. b-d) Micro structure of HAZ of samples with 95% Ar-5%CO₂, 80%Ar-20%CO₂ and 60%Ar-40%CO₂ respectively. e-f) Micro structure of weld zone of samples with 95%Ar-5%CO₂, 80%Ar-20%CO₂ and 60%Ar-40%CO₂ respectively.
In as heat treated condition, base metal has tempered martensite. In the Heat Affected Zone of the material welded with the shielding gas composition of 60% Ar-40% CO$_2$, there is an initial growth of carbides accompanied by depletion of carbon from the surrounding region which is evident by the plain white structure surrounding the carbide pits. It can be observed the area fraction of δ (delta) ferrite (indicate by plain white unetched regions), which is a soft phase, is little higher than normally observed in other microstructures. The microstructure of the parent metal is the same irrespective of the welding conditions. The microstructure of the parent metal consists of tempered martensite with carbo-nitride precipitates mainly due to the addition of modifiers viz Niobium and Vanadium.

3.2 Microhardness

Microhardness of the welded sample was taken with the aid of Vicker’s microhardness tester and are shown in figure 2a-c. Indentations are made at the pattern of 1mm distance between each indentation from the central axis on either side. The profile takes a valley pattern with lower hardness value at the weld zone and increasing hardness as we progress towards the Heat Affected Zone and again decreases on transitioning to the base metal region. Due to the presence of soft δ ferrite at the weld zone, the hardness records a lower value in comparison with the HAZ. Due to the dissolution of the carbon in the martensite it leads to oversaturation and hence we observe high hardness in the HAZ.

![Microhardness profile of welded sample with 95% Ar-5% CO$_2$, 80% Ar-20% CO$_2$ and 60% Ar-40% CO$_2$ respectively.](image)

Figure 2: a-c) Micro Hardness profile of welded sample with 95% Ar-5% CO$_2$, 80% Ar-20% CO$_2$ and 60% Ar-40% CO$_2$ respectively.
3.3 Corrosion Behavior

Corrosion rate obtained from Tafel extrapolation method is tabulated for H₂SO₄ and HNO₃ for four different normalities in table 4 and 5 respectively. To compare the effect of shielding gas composition on corrosion behavior, graph is plotted for Corrosion rate vs Normality from the values given in the tables and are shown in figure 3 and 4.

**Table 4:** Corrosion rate at weld and base metal in Sulfuric acid.

|          | 0.5N | 1.0N | 1.5N | 2.0N |
|----------|------|------|------|------|
| **Weld metal** |      |      |      |      |
| 95% Ar- 5% CO₂ (e+004) | 1.163 | 1.238 | 1.317 | 1.420 |
| 80% Ar- 20% CO₂ (e+004) | 1.094 | 1.152 | 1.358 | 1.349 |
| 60% Ar- 40% CO₂ (e+004) | 1.203 | 1.255 | 1.345 | 1.539 |
| **Parent metal** |      |      |      |      |
| (e+004) | 1.043 | 1.131 | 1.221 | 1.269 |

**Table 5:** Corrosion rate at weld and base metal in Nitric acid.

|          | 0.5N | 1.0N | 1.5N | 2.0N |
|----------|------|------|------|------|
| **Weld metal** |      |      |      |      |
| 95% Ar- 5% CO₂ (e+004) | 2.289 | 3.296 | 3.949 | 5.711 |
| 80% Ar- 20% CO₂ (e+004) | 2.473 | 3.278 | 3.480 | 5.986 |
| 60% Ar- 40% CO₂ (e+004) | 3.002 | 4.732 | 5.874 | 7.393 |
| **Parent metal** |      |      |      |      |
| (e+004) | 2.200 | 3.263 | 3.747 | 3.894 |

**Figure 3:** Corrosion rate at weld and base metal in sulfuric acid

**Figure 4:** Corrosion at weld and base metal in Nitric acid

From figure 3, of all the joint welded with the shielding gas composition of 60% Ar-40% CO₂ is very high while the base metal records low corrosion resistance. Corrosion rate of the 80% Ar-20% CO₂ has a fluctuating rate of corrosion. From figure 4, the corrosion rate is higher in nitric acid as in comparison
with the observed rate with sulphuric acid. The joint welded with the shielding gas composition of 60%Ar-40% CO₂ is very high while the base metal records low corrosion resistance. Corrosion rate of the 80%Ar -20% CO₂ has a fluctuating rate of corrosion, it reaches a lower corrosion rate than base metal for two different normalities and surges above the 95%Ar-5% CO₂ for higher concentration of corrosive medium. The sample which is welded by using 60%Ar-40% CO₂ has the poor corrosion resistance due to presence of more oxygen in the weldment formed during the disintegration of carbon dioxide at arc plasma.

4. Conclusions

The following are the conclusions drawn from the present study.

- 80%Ar-20%CO₂ weld metal contains high amount of delta ferrite due to that it contain low hardness values.
- The corrosion resistance of the weldments is low in comparison with the corrosion rates of the base metal.
- The sample which is welded by using 60%Ar-40%CO₂ has the poor corrosion resistance due to presence of more oxygen in the weldment formed during the disintegration of carbon dioxide at arc plasma.
- Sample welded with 95%Ar-5%CO₂ shielding gas exhibits favourable microstructural and corrosion behavior which is better than the other two samples.

5. References

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