A Detailed Study on Microstructure and Corrosion Behaviour of Gas Tungsten Arc Welded (GTAW) and Shielded Metal Arc Welded (Smaw) Hastelloy C-276

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Abstract- HASTELLOY C-276 (UNS N10276) is a Nickel-chromium-molybdenum wrought alloy that is considered the most versatile corrosion resistant alloy available. This alloy is resistant to the formation of grain boundary precipitates in the weld heataffected zone, thus making it suitable for most chemical process applications in an as welded condition. So here we examine the corrosion behaviour of the weldment of Hastelloy C-276, which is welded by Gas Tungsten Arc Welding (GTAW) and Shielded Metal Arc welding (SMAW) by using the traditional corrosion testing method i.e immersion corrosion test. The corrosion test is conducted by using Green death solution that acts as the corrosion medium which is a mixture of acids. The solution is heated to boiling, 103 °C (217 °F), for 72 hours. Such a corrosive environment occurs at power plants. Corrosion rate was determined by using weight loss method. Results of the corrosion test were compared between the GTAW and SMAW samples. The microstructural analysis is made on weld zone, heat affected zone and base metal of both the welded samples.

Keywords: ***Hastelloy C-276, Gas Tungsten Arc Welding, Shielded Metal Arc welding, immersion corrosion test, Green death solution, Microstructure.***

I.INTRODUCTION

SHIELDED METAL ARC WELDING (SMAW) PRINCIPLE

Shielded metal arc welding (SMAW) is a welding process in which coalescence of metals is produced by heat from an electric arc maintained between the tip of a consumable electrode and the surface of the base material in the joint being welded. It uses a flux coated electrode that melts and acts as filler material. It also gives off shielding gas and slag to protect the weld area from atmospheric contamination.

WORKING PROCEDURE

To strike the electric arc, the electrode is brought into contact with the work piece by a very light touch of the electrode to the base metal. The electrode is then pulled back slightly. This initiates the arc and thus the melting of the work piece and the consumable electrode, and causes droplets of the electrode to be passed from the electrode to the weld pool. Striking an arc, which varies widely based upon electrode and work piece composition, can be the hardest skill for beginners. The orientation of the electrode to work piece is where most stumble; if the electrode is held at a perpendicular angle to the work piece, the tip will likely stick to the metal, which will fuse the electrode to the work piece, causing it to heat up very rapidly. The tip of the electrode needs to be at a lower angle to the work piece, which allows the weld pool to flow out of the arc. As the electrode melts, the flux covering disintegrates, giving off shielding gases that protect the weld area from oxygen and other atmospheric gases. In addition, the flux provides molten slag which covers the filler as it travels from electrode to the weld pool. Once part of the weld pool, the slag floats to the surface and protects the weld from contamination as it solidifies. Once hardened, it must be chipped away to reveal the finished weld. As welding progresses and the electrode melts, the welder must periodically stop welding to remove the remaining electrode stub and insert a new electrode into the electrode holder. This activity, combined with chipping away the slag, reduces the amount of time that the welder can spend laying the weld, making SMAW one of the least efficient welding processes. In general, the 17 operator factor, or the percentage of operator's time spent laying weld, is approximately 25%. The actual welding technique utilized depends on the electrode, the composition of the workpiece, and the position of the joint being welded. The choice of electrode and welding position also determine the welding speed. Flat welds require the least operator skill, and can be done with electrodes that melt quickly but solidify slowly. This permits higher welding speeds. Sloped, vertical or upside-down welding requires more operator skill, and often necessitates the use of an electrode that solidifies quickly to prevent the molten metal from flowing out of the weld pool. However, this generally means that the electrode melts less quickly, thus increasing the time required to lay the weld.

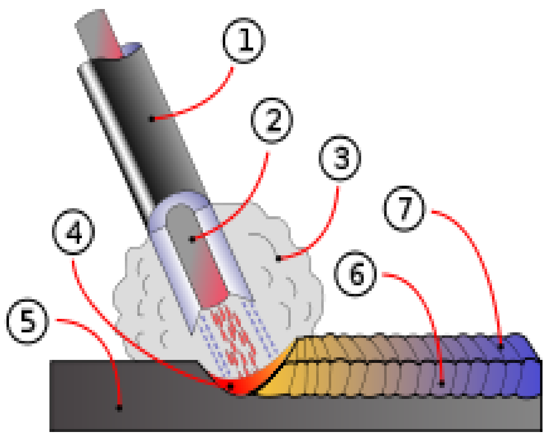

Fig 1.1 Schematic diagram of SMAW

1. Coating flow 2. Rod 3. Shield gas 4. Fusion5. Base metal 6. Weld metal 7. Solidified slag

GAS TUNGSTEN ARC WELDING (GTAW) PRINCIPLE

Gas Tungsten Arc Welding (GTAW) welding works on same principle of arc welding. In a GTAW welding process, a high intense arc is produced between tungsten electrode and work piece. In this welding mostly work piece is connected to the positive terminal and electrode is connected to negative terminal. This arc produces heat energy which is further used to join metal plate by fusion welding. A shielding gas is also used which protect the weld surface from oxidization. A filler metal may or may not be used, which depends on the material to be weld.

WORKING PROCEDURE

Manual gas tungsten arc welding is a relatively difficult welding method, due to the coordination required by the welder. Similar to torch welding, GTAW normally requires two hands, since most applications require that the welder manually feed a filler metal into the weld area with one hand while manipulating the welding torch. Maintaining a short arc length, while preventing contact between the electrode and the workpiece, is also important. To strike the welding arc, a high-frequency generator (similar to a Tesla coil) provides an electric spark. This spark is a conductive path for the welding current through the shielding gas and allows the arc to be initiated while the electrode and the workpiece are separated, typically about 1.5–3 mm (0.06– 0.12 in) apart. Once the arc is struck, the welder moves the torch in a small circle to create a welding pool, the size of which depends on the size of the electrode and the amount of current. While maintaining a constant separation between the electrode and the workpiece, the operator then moves the torch back slightly and tilts it backward about 10–15 degrees from vertical. Filler metal is added manually to the front end of the weld pool as it is needed. Welders often develop a technique of rapidly alternating between moving the torch forward (to advance the weld pool) and adding filler metal. The filler rod is withdrawn from the weld pool each time the electrode advances, but it is always kept inside the gas shield to prevent oxidation of its surface and contamination of the weld. Filler rods composed of metals with a low melting temperature, such as aluminum, require that the operator maintain some distance from the arc while staying inside the gas shield. If held too close to the arc, the filler rod can melt before it makes contact with the weld puddle. As the weld nears completion, the 24 arc current is often gradually reduced to allow the weld crater to solidify and prevent the formation of crater cracks at the end of the weld. The physics of GTAW involves several complex processes, including thermodynamics, plasma physics, and fluid dynamics. The non-consumable tungsten electrode can be operated as a Cathode or Anode and is used to produce an electric arc between the electrode and the workpiece. In order to initially create the arc, the welding area is flooded with inert gas and a high strike voltage (typically 1 kV per 1 mm) is generated by the welding machine to overcome the electric resistivity of the atmosphere surrounding the welding area. With the arc established, the voltage is lowered and current flows between the work piece and electrode. Despite the high temperatures of this electric arc, the main heat transfer mechanism in GTAW is the joule heating resulting from this current flow.

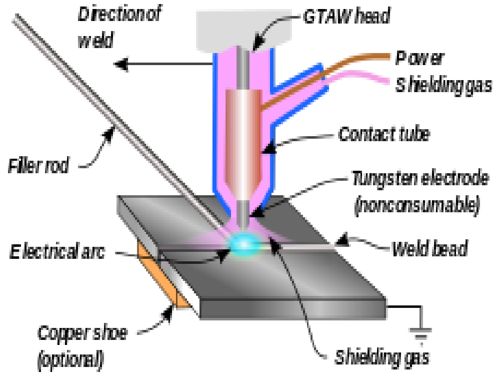

Fig 1.2 Schematic diagram of GTAW

II. LITERATURE SURVEY

1. Sumitra Sharma et al., studied the Influence of Filler Material Composition Corrosion Behaviour of C-276. Four different filler materials (ERNiCrMo-4, ERNiCrMo-10, ERNiCrMo-3 and ERNiCr-3) in combination with pulsed current gas tungsten arc welding to join 6 mm sheets of C-276. Pitting behaviour of the welds was also evaluated by an immersion test (modified Huey test). The specimen is immersed in a boiling solution of 65% HNO3 + 0.1% HF for 4h. The results shows that the density of the pitting holes was observed to be lesser for ERNiCrMo-4 FZ followed by ERNiCrMo-10, ERNiCrMo-3 filler. The condition was quite worse for ERNiCr-3 weld as can be seen. The welds fabricated by ERNiCr-3 filler resulted in cracking of the welds. It shows C-276, ERNiCrMo-4 filler (followed by ERNiCrMo-10 filler) can be used for better result.

2. Er. Rahul Sharma et al., examined the corrosion behaviour of the Hastelloy C-276 weld overlay by Shielded metal arc welding (SMAW). For overlay the base material chosen was SA 516 grade 70. The electrode chosen was ENiCrMo-4 of 3.2mm diameter. It was multilayer cladding and weld bead height is 6mm. The corrosion test was done by immersion test using two methods namely, corrosion test as per ASTM G-28 B for 24 hours. The weight loss was found to be 0.0667g (0.70mg) and corrosion testing as per ASTM G-48 B for 24 hours. The weight loss is found to be 0.0015g (1.50mg).There was no crevice crack observed on the surface at 20x magnification.

3. Kalinga Simant Bal et al., Investigated the intergranular corrosion behaviour of electron beam welded Hastelloy C-276 sheet using laser displacement sensor by method A of ASTM G-28. The sample was immersed in 600ml of ferric sulfate-50% sulphuric acid for 24 h at the boiling temperature of 125_C. The CR was calculated by applying formula of ASTM G-28. The average corrosion rate of Hastelloy C-276 samples was found to be 6.47 ± 0.20 mm/y. Analysis of the corrosion rate for each zone shows that WZ>BM>HAZ. The corrosion rate for each zone varies in the ratio as WZ: BM: HAZ = 3.44: 1: 0.55.

4. M. manikandan et al., studied the corrosion on Pulsed Current Gas Tungsten Arc Welded Alloy C-276. Investigation has been carried out on Pulsed Current Gas Tungsten Arc Welding by autogenous and different filler wires (ERNiCrMo-3 and ERNiCrMo-4) under molten state of K2SO4–60% NaCl environment at the temperature of 675oC. It is observed autogenous weldment has proved to be the most corrosion resistant in the aggressive environment. It is also noted that the autogenous weldment has slightly less corrosion resistance as compared to base metal in the same environment. Corrosion rate of the specimen under study can be arranged in the following order: ERNiCrMo-3 > ERNiCrMo-4> Autogenous > Base C-276. The result showed that weld fabricated by ERNiCrMo-3 found to be more prone to degradation than base metal.

5. Ajit Mishra compared the corrosion resistance of Iron alloys and Nickel alloys using immersion corrosion test in different types of acidic solution. For immersion test using HCL and H2SO4 wrought samples of Fe and Ni based alloys 32 are choosed. And in both the type of acidic solution the corrosion resistance of C-276 alloy is higher than the Fe alloys and Ni alloys. The corrosion rate of C-276 came out like 0.003-0.31 mm/year in HCL. Another immersion test was conducted on the BM, HAZ and WZ of Gas Metal Arc welded Hastelloy C-276 using ERNiCrMo4 sample by using ASTM G-48 C. the corrosion rate of BM, HAZ, AWM are 0.10, 0.13, and 0.33 respectively. The critical pitting temperature was found to be 120_C for BM and HAZ. For AWM, CPT is 110_C and resulted in pit propagation.

III. EXPERIMENTAL WORK

WELDING BY SMAW

The welding of 2 mm thick Hastelloy C-276 by SMAW is a simple process because it has great weldability when welded by respective alloy electrodes. It is carried out by ADOR Champ T400 SMAW machine. It is welded by square butt joint and by flat position (1G). The respective alloy consumable used is electrode AWS A5.11, ASME SFA A5.11 ENiCrMo-4 of 2.5 mm diameter. Reverse polarity DCEP is used. The welding process is carried out by determining the process parameters and SMAW works with the constant current and the constant current is determined by the diameter of the electrode as well as the welding position. The electrode size is governed by the thickness of the metal.

From the process parameter the welding is carried out by Shielded Metal Arc Welding (SMAW). The slag is removed.

WELDING BY GTAW

The welding of any material by GTAW is a tough process. So it requires a high skilled labour. The welding of 2 mm thick Hastelloy C-276 sheet can be carried out by using respective alloy consumables or filler wire. It is carried out by KEMPPI MASTER TIG ACDC 3500W GTAW machine. As SMAW, it is also welded by square butt joint and by flat position (1G). The respective alloy consumable used is filler wire AWS A5.14, ASME SFA A5.14 ERNiCrMo-4 of 2.40 × 1000 mm. Straight polarity DCEN is used. The welding process is carried out by determining the process parameters and GTAW also works with the constant current and the constant current is determined by the diameter of the filler wire as well as the welding position. The size of filler wire is governed by the thickness of the metal. From the process parameter the welding is carried out by Gas Tungsten Arc Welding (GTAW).

IV. TESTING OF MATERIALS

For both corrosion testing and microstructure analysis the welded sample size should be smaller, so the material of 2×65×65 mm is cut to 2×10×30 mm by using abrasive cutting with coolant oil.

MICROSTRUCTURE ANALYSIS

The sectioned samples with 2×10×30 mm dimension are subjected to mechanical polishing to make sure that the surface must be without scratches or deformation for microstructural analysis.

The mechanical polishing includes –

- Course grinding machine – grade 40, 50.
- Fine grinding machine - grade 180, 280, 400, 600, 800.
- Disc polishing machine – velvette cloth from herbaen with alumina gives mirror finish to the surface.
- Etching – etching is a chemical attack on the surface. Etching is chemical or electrolytic process after polishing, etching enhances the contrast on surfaces in order to visualize the microstructure and macrostructure. Here we use electrolytic etching with Acetic acid – 5 ml, Nitric acid – 10 ml, water – 85 ml.
- Microscopic examination – the polished sample is placed in an optical microscope.

IMMERSION TEST WITH GREEN DEATH SOLUTION

The immersion test in done in green death solution in the SMAW and GTAW welded samples for 72 hours and in the boiling temperature of 103oC. The sectioned samples with 2×10×30 mm dimension of rectangular shape is subjected to hot corrosion were sliced with weld as centre, the region consists of weld zone (WZ), heat affected zone (HAZ) and base metal (BM). The SMAW and GTAW samples used for corrosion test is subjected to mirror polishing by means of 120 grid abrasive paper and wet grinding. Then the samples are cleaned by scrubbing with bleach-free scouring powder, followed by thorough rinsing in water and in a suitable solvent (such as acetone, methanol, or a mixture of 50 % methanol and 50 % ether), and air dried. Then the samples weight are measured to note the initial weight before immersion of the sample. The weights are measured using electronic weighing balance from Essae / FB-200 with the range of 0-200 g to the nearest 0.001g. Now preparation of the corrosion medium i.e the Green Death solution. The volume of the solution is fixed by ASTM G3 as 350 ml with respect to the dimension of the sample. The 350 ml green death solution is taken in the BOROSIL with the range of 25- 500 ml, LC – 5 ml. The Borosil is kept in the furnace for boiling because the temperature of the test is 103oC. The temperature of the solution is found by using glass thermometer from RT. Once 103oC is attained in the solution the GTAW and SMAW prepared samples for corrosion test is immersed in the Green Death Solution. The test duration is 72 hours, the samples are kept undisturbed for the whole duration. After 72 hours the welded corroded samples are taken out from the solution. The corroded samples are then cleaned by rinsing in water and in a suitable solvent (such as acetone, methanol, or a mixture of 50 % methanol and 50 % ether), and air dried. Now, the final weight of the sample is noted by using the same electronic weighing balance. Weight loss is measured from subtracting the initial weight from the final weight. Surface area is calculated from the dimensions of the sample. Time duration of test is already known. Hence the corrosion rate can be found from the corrosion test.

V.CONCLUSION

The microstructure of SMAW sample shows coarse cellular dendrite grains, high M23C6 carbides and larger precipitate in WM and HAZ but In GTAW sample, it shows fine equiaxed dendrite grains, low M23C6 carbides and uniform precipitates so it has increased the strength and corrosion resistance of the GTAW sample. The macrostructure of the SMAW and GTAW sample showed how much the surface of the sample is corroded. It can be concluded that GTAW sample shows less corrosion rate and pit rate than SMAW sample. So GTAW can be used for welding Hastelloy C-276 2mm thick which are to be subjected to harsh environments like Green death solution.

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