Scientific Journal of Impact Factor (SJIF): 4.14
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406

International Journal of Advance Engineering and Research Development

Volume 3, Issue 8, August -2016

Review on Electro-Slag Strip Cladded Weld Overlays

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Abstract- *Large pressure vessels are used in hydrogen containing environments, for example, in the petroleum industry in hydro-cracking, hydrodesulphurization and catalytic reforming processes as well as in the chemical and coal conversion industries. All hydro processing reactors made of low carbon low alloy steel or Cr-Mo steel which require internal protection of the reactor vessel walls experience electrochemical corrosion such as pitting corrosion, inter-granular corrosion, stress corrosion cracking & hydrogen disbonding. Due to their excellent mechanical properties with good corrosion resistance and heat resistance, corrosion resistant alloys such as austenitic stainless steel and nickel based alloys are very suitable for the cladding of such pressure vessels in the petrochemical industries. The two most productive systems for surfacing the large components which are subjected to corrosion or wear are submerged arc and electro- slag cladding, using a strip electrode. Both processes are characterized by a high deposition rate, low dilution and high deposit quality. Both these processes are suitable for surfacing flat and curved objects such as heat exchanger tube sheets and pressure vessels. Submerged arc welding (SAW) is most frequently used but, if higher productivity and restricted dilution rates are required, electro-slag welding (ESW) is recommended.*

Keywords-*electroslag strip cladding ,welding parameters, post weld heat treatment*

I. INTRODUCTION

Cladding is a process to deposit a fine layer of a material using strip or filler electrode that is fused under an agglomerated flux onto a non-alloyed or low-alloy base material to get good corrosion resistance, wear resistance & high hardness surface[1-2]. Cladding of carbon or low alloy steel can be accomplished in several ways including roll bonding, explosive bonding, weld overlaying or hard facing. Stainless steel strip cladding is a flexible & economical way of depositing corrosion resistant, protective layer on low alloy or low carbon steel due to which it is widely used in the production of components for chemical, petrochemical & nuclear industries [3]. Large pressure vessels are used in hydrogen containing environments, for example, in the petroleum industry in hydro-cracking, hydrodesulphurization and catalytic reforming processes as well as in the chemical and coal conversion industries [4].Many reactor vessels operate at high temperatures and at high hydrogen partial pressures, with 450°C and 15 MPa often being mentioned as typical values The vessels are generally fabricated from low alloy, creep resistant steels [5-6].All hydro processing reactors require internal protection of the reactor vessel walls to resist the high temperature corrosion due to presence of sulphur in the process stream. This protection is generally provided by stainless steel strip electrodes which are made up of different grade such as 347,309L, 309LNb, 316L, 317L. A stabilized composition overlay also prevents sensitization during the final post weld heat treatment (PWHT) cycle of the reactor .The two most productive systems for surfacing large components which are subjected to corrosion or wear are submerged arc and electroslag cladding, using a strip electrode. Both processes are characterized by a high deposition rate, low dilution and high deposit quality, and they are both suitable for surfacing flat and curved objects such as heat exchanger tube sheets and pressure vessels. Submerged arc welding (SAW) is most frequently used but, if higher productivity and restricted dilution rates are required, electroslag welding (ESW) is recommended [7].

II. METHODOLOGY

2.1 Basic Principle of the ESSC Process

Electroslag strip cladding is a development of submerged arc strip cladding which has established itself as a reliable high deposition rate process. The process is initiated by starting an electric arc between the electrode and the base metal which results in initial melting the flux. The Molten slag became electro conductive due to the presence of special ingredient and it will support the passage of current at lower voltage and the arc gets extinguished. [8]. As soon as sufficiently thick layer of molten slag is formed, all arc action stops .A strip electrode is continuously fed into a shallow layer of molten electro conductive slag. The heat which is needed to melt the strip, slag forming flux and the surface layer of base metal is generated by the Joule effect as a result of the welding current flowing through the liquid electro conductive slag. Heat generated by the resistance of the molten slag to passage of the welding current is sufficient to fused the surface of the work piece and the strip electrode. The interior temperature of the bath is in vicinity of 19250 C while the surface temperature is approximately 16500 C. Melted electrode and the base metal collect in pool beneath the molten slag bath and slowly solidify to form the clad [9].

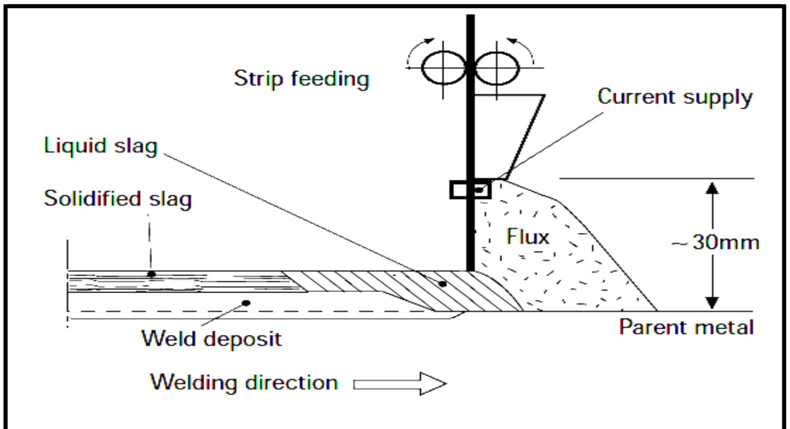

Fig.1. Schematic Diagram of ESSC Process

2.2 Characteristics of ESSC

- Electro-slag strip cladding is the modified version of submerged arc strip cladding process.
- The heat generation in the case of ESSC is due to the current flowing through the electro-conductive slag.
- Molten weld pool will be visible during welding.
- Radiation only in the visible and infrared spectrum. No ultraviolet radiation because of the absence of the arc.
- Flux fed from front side only.
- Automatic removal of the slag crust.
- Very regular, finely ripped bead, without any slag adherence.
- Low arc voltage (24 – 26V)
- Can be applied on curved as well as flat surfaces.
- Low flux consumption. (0.4 -0.5 Kg/Kg strip).

2.3. Advantages of the Electroslag strip cladding process :

- Low dilution by the base metal
- Higher melting rate (Rmelt)
- Higher deposition rate (Rdep)
- Low flux consumption
- Smooth bead surface with a higher degree of purity [10].

2.4 Limitations of the Electroslag strip cladding process :

- Weld in the flat or downhand position
- Adequate access for the welding head
- The overlap between adjacent beads must be controlled to avoid lack of fusion defects.
- The chemical composition & welding parameters of the strip must be carefully selected to take into account the level of dilution[11].

2.5 Application of Electroslag Strip Cladding Process

- Nuclear Power Components (marine environments)
- Petro Chemical Industry (High temp, high pressure)
- Chemical industry. (High temp, high pressure)
- Offshore Industry. (seawater environments)
- Paper industry. (aggressive service environments.)

- See Water Desalination Plants. (seawater environments)
- Waste Water processing
- Desulphuration Plants. (acidic environments)
- Surfacing of Continuous Casting Rollers. (high pressure) [12-13].

III. WELDING PARAMETERS OF ESSC PROCESS

3.1 Welding Current:

Due to absence of an arc, the penetration in the ESSC process is very shallow; this means that there will be little mixture of the filler metal with the melted base material. The current level is the single most important factor controlling the deposition rate in the electroslag process. Both deposition rate and penetration rate are found to increase with current in a linear manner. Since the dilution is dependent upon the deposition rate and penetration, the combine effect of both factors resulted in variation in the dilution. The slight drop in dilution with increasing current can be explained by the interaction between growth in bead thickness, width and penetration. At the low current density, the surfacing layer developed undercutting, while excessive current density had either the short circuit at low voltage or the melt back at high voltage [14].

3.2 Welding Voltage:

The welding voltage should be accurately control because it affects the specific resistance of the liquid slag and will determine how far the strip electrode is to be submerged in the slag pool. Insufficient immersion in the weld pool will cause the process to become unstable. The welding voltage must be lowered as current rises. A range of 24 to 26 V when operating at 1250 A, or 22 to 24 V for 2500 A, is normal. At voltage below 24 V, the strip electrode has tendency to strike to the base metal and resulting in short circuiting and hence the process become unsuitable. At above 26 V, the amount of slag spatter increases rapidly while at about 28 V and above it the process stared arcing on the surface of the flux and slag spatter become violent. The exact value will depend on the properties of the flux and the dimensions of the strip. At given welding current and welding speed, the dead thickness and width and penetration / dilution of the base metal vary with the voltage .The slag spatter tendency can also be controlled by depth of flux, but in order to maintain the flux consumption at lowest possible level, the depth of the flux burden should not exceed 35 mm.

3.3 Welding Speed:

The electroslag strip cladding process was stable only when sufficient contact area between the molten slag pool and the melting strip was maintained. An excessive fast travels speed caused the strip to be in contact with insufficiently heated slag, thus resulting in sporadic submerged arcing and process instability. Excessive travel speed resulted in not only an overlay thickness but also the formation of undercutting. On the other hand, too slow a travel speed resulted in bead thickness increase with an accompanying wetting angle so steep that slag entrapment may occur at the bead overlaps[15]. At given welding current and voltage, the bead thickness, bead width and penetration or dilution of the base metal vary with welding speed as illustrated by fig.2.14. The welding speed has a considerable influence on bead geometry and dilution. The increasing welding speed can be explained by the interaction between decreased bead thickness, width and increased penetration. Heat transferred to the base metal is influenced by the relative location of the strip electrode and the molten metal pool.

3.4 Stick out:

The stick out is the length of the free strips electrode end from the contact jaws to the parent metal. It may vary between 25 and 40 mm without affecting the stability of the process. A variation with in this range does not influence bead geometry, penetration or dilution and deposition rate to any large degree.

IV. POST WELD HEAT TREATMENT OF ELECTRO-SLAG STRIP CLADDED WELD OVERLAYS

Post weld heat treatment (PWHT), defined as any heat treatment after welding, is often used to improve the properties of a weldment. In concept, PWHT can encompass many different potential treatments; however, in steel fabrication, the two most common procedures used are post heating and stress relieving.

4.1 Effect of Post weld heat treated on microstructures of weld overlay:

Post- weld heat treatment (PWHT), is used to decrease residual stress levels & improve the ductility of weld overlay [16]. However, during PWHT, carbon diffuses from the low steel to the austenitic weld overlay generating a decarburized layer in the low alloy steel adjacent to the interface and a carbon-enriched layer in the nearby weld overlay. Most of the carbon in the carbon- enriched zone precipitates as carbides, thereby decreasing the dissolved Cr concentration in the matrix. These micro structural changes, which depend on the PWHT temperature and duration and on the chemical composition of the two metals, cause changes in mechanical properties. Phase transformation or precipitation of carbides may occur in the metastable austenite/ferrite weld overlay during PWHT process. The formation of intermetallic compounds during PWHT may affect the pitting corrosion behavior [17]. During post weld heat treatment for 16 h at 7000 C, several diffusion-based reactions occur in the cladded joint, especially at and near the weld interface. Fig.2 is a micrograph of the interface region after PWHT in the single-layer overlay. It shows a heavily dark-etching layer marking the transition zone between the base metal and bulk weld metal. This was the region which exhibited a martensitic structure in the as-welded condition and in which considerable carbide precipitation has occurred during PWHT. Next to this layer on the clad metal side is a region of weld metal showing the total absence of ferrite. This fully austenitic region is bounded on the other side by a grain boundary running approximately parallel to the dark-etching layer and the weld interface. This grain boundary has been referred to in the literature as a ‘Type II boundary’ [18-19]. Further into the weld metal on the left of the Type II boundary is the more usual austenitic weld metal structure containing ferrite in the substructure boundaries within the austenite grains. The boundaries of these austenite grains represent the conventional or Type I grain boundaries. In Fig. 3 on the base metal side of the dark-etching interface layer exhibits a nearly totally decarburized base metal structure. Note also that the ferrite grains here are able to grow to large sizes in the absence of the carbide phase. Carbon in this region has diffused from the base metal toward the overlay because of the concentration gradient and its affinity for the higher Cr content in the clad metal[20-21].

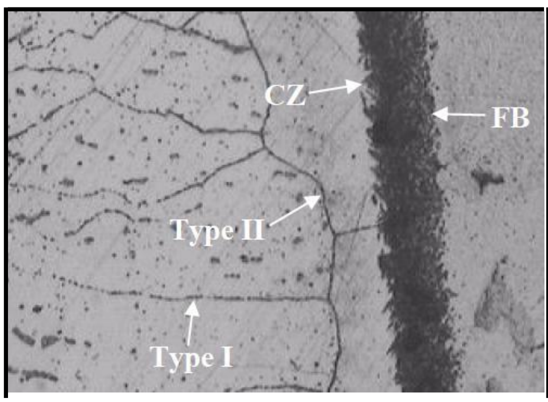

Fig. 2. Weld interface in single layer cladding after PWHT

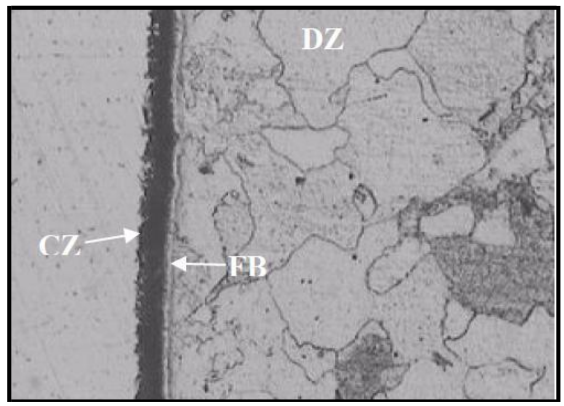

Fig.3 Base metal region adjoining weld interface in single layer cladding after PWHT

4.2 Effect of PWHT on Micro hardness of Weld Overlays

The microhardness distributions across the weld interface both in the as-welded condition and after PWHT are plotted in Fig.4. In the as-welded condition, there is a moderate increase in hardness at the weld interface region, which can be attributed to the formation of a low-carbon martensite. After post weld heat treatment the hardness of this region registers a significant increase, presumably as a result of heavy carbide precipitation. On the base metal side of the interface after post weld heat treatment, there is a noticeable softening effect as a result of the migration of carbon from this region to the interface.

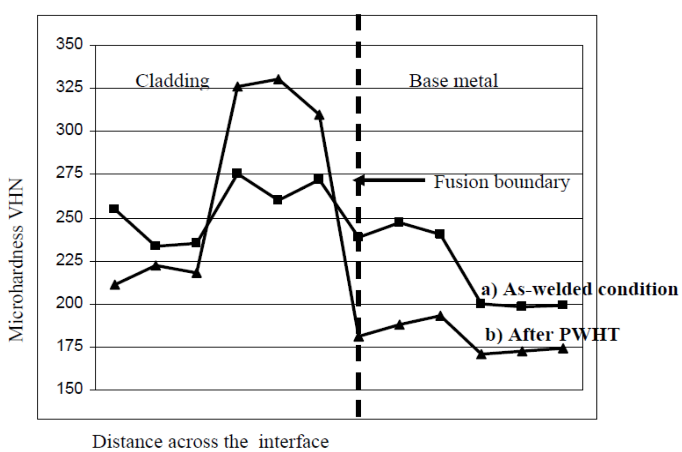

Fig. 4 : Microhardness distributions across clad interface

Double PWHT procedures have been developed to significantly decrease the hardness of the interface region of claddings, compared to the hardness measured after a single PWHT. With a tempering in two steps lower hardness values are to be found, compared to a single PWHT due to annealing of the fresh martensite formed during cooling.

V. PROBLEMS & ISSUES RELATED TO ELECTRO-SLAG STRIP CLADDED WELD-OVERLAYS

5.1 Hydrogen disbonding in weld overlays

The operating conditions can vary significantly in hydrogen reactors, ranging from 200-600°C under hydrogen partial pressures of 1-60 MPa with 450°C and 15 MPa often being mentioned as typical values. During steady-state operating conditions in hydrogen reactors, there is a higher hydrogen concentration in the austenitic cladding than in the ferritic parent metal. When the reactor is cooled during shutdown, hydrogen attempts to diffuse from the steel. The lower solubility and higher diffusivity of hydrogen in the parent metal, compared with that in the austenitic cladding, leads to the build up of high hydrogen concentrations locally at the interface between the parent metal and the weld surfacing layer. Local over-saturation of hydrogen in combination with sensitive microstructures is known to cause hydrogen induced cracking (disbonding) in this region . The exact mechanism of disbanding is under discussion, but it is thought to occur essentially as a result of hydrogen embrittlement. It is clear, however, that the resistance to disbonding is affected by the interface region microstructure and is therefore dependent on the applied PWHT. Weld overlay disbonding has been observed, in somecases, during cool down of reactors. Crack propagation occurs in a narrow zone at the interface and along grain boundaries in the overlay close to the interface (Fig. 6).

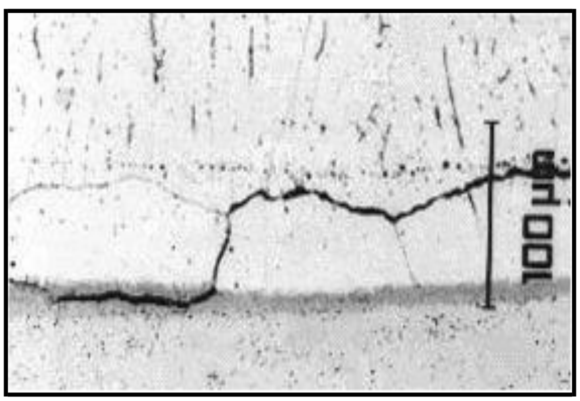

Fig. 5 Disbonding in the interface region between parent material (bottom) and an austenitic overlay weld metal

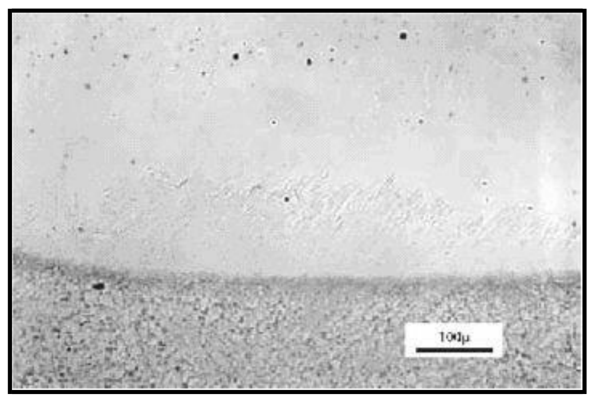

Fig. 6 Martensite (light etching) at parent metal/ weld overlay interface

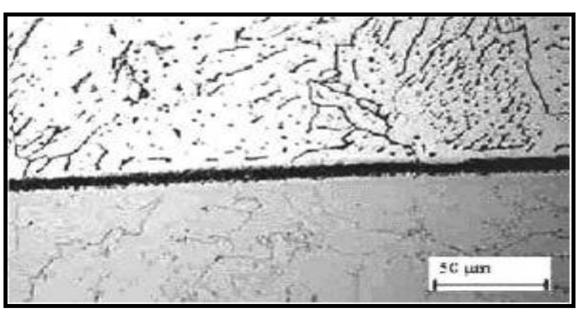

Fig. 7 comparatively narrow dark etching band of tempered martensite and carbides seen in an electroslag welded overlay after PWHT

Fig. 5-7 gives some examples of interface region micro structures showing a band of tempered and/or un-tempered martensite and carbides typically found next to the interface. A ferrite-free region of typically 20 – 100 µm width separates the parent material from the normal ferrite-containing weld metal structure. A narrow band of martensite appears clearly in the weld overlay interface region in the as-welded condition (Fig. 7). The structure of the interface region for post weld heat treated welds consists mainly of tempered martensite and carbides (Fig. 2.58). However, the higher hardness produced by a single PWHT as compared to double post weld heat treatment cycles suggests that fresh martensite can form during cooling from the PWHT temperature. Significant carbon migration is taking place during PWHT, as can be seen from the carbide precipitation and the formation of a 150 – 200 µm wide decarburised zone in the parent material (Fig. 2.58). The grain boundaries are also decorated by carbides in, and next to, the interface region[22,23].

5.2 Minimizing Disbonding Susceptibility:

Vessel wall material: As a first step, the base metal must be resistant to high temperature hydrogen attack, which can be ensured by selecting clean steels containing low levels of impurities (i.e. P, S and trace elements). A decreased carbon content also acts to reduce the amount of carbon diffusion into the overlay. The newer, vanadium modified Cr-Mo steels tend to have a lower susceptibility to hydrogen effects. This is claimed to be an effect of finely dispersed vanadium carbide precipitates trapping the atomic hydrogen. Consequently, there is a lower diffusivity of the hydrogen in the steel and the accumulation of hydrogen at the transition zone is lower compared to conventional Cr- Mo steels. Testing of double layer SAW and single layer ESW strip claddings of the 347 type, confirmed the excellent disbonding resistance of V-modified steels [23].

VI. CORROSION ISSUE IN ELECTRO-SLAG STRIP CLADDED WELD OVERLAY

Generally, all hydro processing reactors require internal protection of the reactor vessel walls to resist the high temperature corrosion as well as pitting & IGC due to presence of various corrosive process streams. This protection is generally provided by stainless steel strip electrodes which are made up of different grade such as 347,309L, 309LNb, 316L, 317L. Weld overlay subjected to the Post-weld heat treatment (PWHT), at 6900C for prolong period of time to decrease residual stress levels of the base metal & improve the ductility of the cladding. But, the formation of inter-metallic compounds such as chromium carbide and sigma phase during PWHT may affect the pitting corrosion & IGC susceptibility of weld overlay and hence 309 L or 309L Nb austenitic stainless steel strip is used as cladding materials for such reactor vessel. The welding speed has a considerable influence on bead geometry, ferrite content, dilution & micro-structural changes of the weld overlay. Weld overlay developed at low welding speed has low dilution but at the same time it acquiring an unacceptable high content of ferrite & course grain structure which intern lead to increase the susceptibility towards IGC. Whereas, higher welding speed would produce an overlay with finer grain structure due to the faster cooling rates in the fusion region, which may lead to the inhibition of the formation of planar grain boundaries and hence decrease in susceptibility towards IGC[24,25].

VII. CONCLUSIONS

- Electro slag strip cladding is an advancement of submerged arc strip cladding due to low dilution, high deposition rate and low flux consumption.

- Out of all welding parameters, welding speed has great influence on dilution, bead geometry and micro-structural changes and mechanical properties. With lower welding speed low dilution but acquiring an unacceptable high content of ferrite & course grain structure of weld metals while with increase in the welding speed finer microstructure obtained leading to less ferrite formation ,higher hardness values and higher dilution percentage but reduce the concentration of impurities on grain boundaries.

- Post- weld heat treatment (PWHT) is used to decrease residual stress levels & improve the ductility of weld overlay However, during PWHT, carbon diffuses and generating a decarburized layer in the low alloy steel adjacent to the interface and a carbon-enriched layer in the nearby weld overlay. The formation of intermetallic compounds during PWHT may affect the pitting & inter-granular corrosion behavior of weld overlay.

- Disbonding is due to hydrogen embrittlement and is associated with the presence of martensite in the interface region; the martensite forming both during welding and following postweld heat treatment.Disbonding resistance was improved by double postweld heat treatments, avoiding low ferrite in the first-layer deposits & use of V-modified parent steels.

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