Monitoring of Lack of Bond in a Cladded (Alloy 825) Carbon Steel Vessel by Ultrasonic Phased Array Longitudinal Waves.

Santanu Saha¹, Amaresh Majumder² and Shan Castelino³
¹International Inspection Services Ltd. PO Box 96535; Dubai; United Arab Emirates.
²International Inspection Services Ltd. PO Box 96535; Dubai; United Arab Emirates.
³International Inspection Services Ltd. PO Box 96535; Dubai; United Arab Emirates.
¹ssaha@int-inspec.com; ²Amaresh@int-inspec.com, ³mcastelino@int-inspec.com

ABSTRACT
Routine in-service examination during shut down of a cladded pressure vessel for toxic service indicated presence of large flaws at the interface between base metal and clad metal. The vessel is a high pressure vessel for toxic gas service named as high pressure separator. Ultrasonic Phased Array with 64 elements linear Arrays was used to detect any service induced flaws, typically HIC or similar type of discontinuities. Scanning zones were selected randomly by Owner; however during scanning in a selected shell course, indications at the interface of base metal and clad could be noticed and reported. In accordance with Owner’s requirements, the indicated zone shall be examined regularly to monitor the propagation behavior of the disbonded area. On regular scheduled examinations, it has been confirmed that the dis-bond has propagated considerably. Although this method of monitoring is not a new method for such activities, application of automated phased array gave a quite accurate mapping of flaw with higher confidence level and facility for recording and storing for future reference. A propagation map has been created to submit the owner for their understanding and further action on repair schedule based on API 580 RBI criteria and API 579-1/ ASME FFS-1 recommended practice.

Keywords: Ultrasonic Phased Array, Clad Dis-bond, Risk Based Inspection (RBI), Fitness for service (FFS), linear array.
INTRODUCTION:
During routine in service inspection of a high pressure separator (ASME U2 stamp vessel), indications at the clad/ base metal interface could be noticed. The vessel is in toxic liquid service for the past 12 years or more. During installation it was fully inspected, examined in accordance with ASME Sec VIII Div. 2 and Owner’s specification and certified to be acceptable for intended service. The vessel is clad with INCOLOY 825; however, clad thickness (3mm) is not part of the design thickness, so bond integrity check (Lack of bond at clad base metal interface) is not a code requirement. Previous documentation did not indicate whether any examination has been done to verify the clad to base metal bond integrity. Even if the clad base metal bonding has been examined, there are some relaxation in the acceptance criteria in accordance with ASTM A 578 which allows a maximum of 1 inch² of lack of bond can be accepted as individual indication. The present study has been intended to monitor whether the lack of bond area which was detected during routine inspection is propagating in nature or not. This will help in analyzing the type indication, its source and characteristics to plan for future course of action. Use of Phased Array technology for precise sizing and locating the flaw helped us to properly monitor as per the Owner requirements.

VESSEL DATA:
Name: High Pressure Separator
Service: Toxic Liquid
Design pressure: 8.4MPa
Design temperature: 90°C minimum to 195°C maximum.
MDMT: -4°C
Shell thickness: 113mm
Shell material: ASTM A 265M (Base metal: A 516 Gr. 65; Clad: ASTM B 424).

CLADDED PLATES:
Cladding is usually applied by a manual, or an automatic welding process, or by an explosive or rolling process and it is identified by that process. Each process produces a characteristic metallurgical grain structure which influences the passage of ultrasound. Manual metal arc cladding is normally used to join up the cladding on the different parts, because it can be deposited in any position. Manual metal arc cladding is also used to make the cladding continuous where there is a change in section, such as between a vessel shell and a nozzle. The grain structure of all fusion welded austenitic cladding is coarse and anisotropic. The anisotropy is due to the austenitic weld metal solidifying with the <100> crystallographic axis along the direction of the maximum thermal gradient, which is approximately perpendicular to the surface (with a slight tilt towards the welding direction). Therefore columnar grains grow in this direction. Since no phase transition occurs in austenitic weld metal upon cooling there is no grain refinement as in ferritic weld metal and large grains result. Strip cladding is applied by means of an automated welding process and it is used for cladding large surfaces. The width of a strip can vary from 30 mm to 150 mm. Dilution of weld metal by base metal is Single layer strip cladding is used but double layer cladding is more common to reduce the risk of reheat cracking in the base metal beneath the cladding and also to provide improved corrosion protection than is provided by one layer.
STRIP CLADDING FLAWS:

During Manufacture: The main manufacturing defects which can occur in strip cladding are the lack of bond between clad and base metal interface. The reason behind the Lack of Bond is inadequate heat input to melt parent plate, or a layer of cladding. Contamination by scale or rust preventing fusion may also contribute to the lack of bond.

In-service: erosion or aggressive corrosive species may contribute to the loss of cladding thickness or pitting penetration of the cladding will result in rapid corrosion of the base metal and spalling of the cladding.

DETAILS OF EXAMINATION:

Ultrasonic Phased Arrays with 64 elements have been used for scanning; the equipment used is Omniscan MX with 5L 64 A2 linear array search units attached with a wedge of zero degree (SA2 0L IHC 5L64). The examination area was previously marked during initial examination when the location was first identified. Examination has been performed periodically (6 months interval) since 2011 on the same location. It has been observed that there is a gradual increase in the length and width of the indications. Mainly there are two indications representing two dis bonded areas at the same location (refer figure-1). One area has been mapped as 33408 mm² and the other area has been mapped as 1015 mm² during initial examination. On subsequent examinations until April 2013, the first area has grown to 35370 mm² (6% growth) whereas the second area has grown to 4964 mm² (390% growth). It can be noticed that the growth rate of the larger flaw is very less compared to the smaller flaw. Moreover, no growth has been noticed in any of the locations after August 2012. Refer to table-1 for details of observation. Refer also to figure -1 for examination parameters.

<table>
<thead>
<tr>
<th>FLAW NO.</th>
<th>REPORT NO.</th>
<th>Date of Inspection.</th>
<th>Minimum THK Found</th>
<th>FLAW DETAILS</th>
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<td></td>
<td></td>
<td></td>
<td>Length (mm)</td>
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<td>113.9mm</td>
<td>261</td>
</tr>
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</tr>
<tr>
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<td>113.9mm</td>
<td>270</td>
</tr>
<tr>
<td>1</td>
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<td>11-08-2012</td>
<td>113.9mm</td>
<td>270</td>
</tr>
<tr>
<td>1</td>
<td>D/GASCO/PA/010</td>
<td>18-04-2013</td>
<td>113.9mm</td>
<td>270</td>
</tr>
<tr>
<td>2</td>
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<tr>
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<td>113.9mm</td>
<td>68</td>
</tr>
</tbody>
</table>

Table – 1: Comparison of Growth of flaws
Figure-1: Examination details

**MONITORING OF FLAWS:**
There are basically two areas of disband could be observed in the entire vessel shell and dished ends. One area has been mapped as 33408 mm² and the other area has been mapped as 1015 mm²
during initial examination. On subsequent examinations until April 2013, the first area has grown to 35370 mm$^2$ (6% growth) whereas the second area has grown to 4964 mm$^2$ (390% growth). Although the first area is comparatively much bigger than the 2nd area, the rate of growth for the first area is very less (1241 mm$^2$ per year during a period of 1.58 years) as compared to the rate of growth of the 2nd area (3645 mm$^2$ per year during a period of only 1.08 years). It can also be noticed that the first flaw has started growing from January 2011, whereas the 2nd flaw has started growing only from July 2011. No growth of the 2nd flaw has been noticed during the period from January 2011 to July 2011. Surprisingly both the flaws have been noticed to stop growing after August 2012. Refer to the flaw monitoring chart below (figure-2). See also figure-3 for details of measurement done. A series of A-Scan presentations have been included in Appendix – 1 for reference.
HYDROGEN DIFFUSION:
To resist corrosion by the process environment, high pressure separator type vessels require protection for the vessel walls. This protection which is to resist the high temperature corrosion effects of sulphur in the process stream is generally provided by stainless steel or high Alloy cladding/ weld overlay. The cladding/weld overlay that is normally employed is a nominal 18%Cr-8%Ni composition or Inconel and is usually deposited in two to three individual deposition passes. This overlay system provides an excellent protection against corrosion, and the stabilized type 347 overlay provides protection from sensitization during the final post weld heat treatment (PWHT) cycle of the reactor. The ferrite content in the weld overlay plays an important part in the integrity of the clad/ weld overlay.
WELD OVERLAY/ CLAD DISBONDING:
Weld overlay dis-bonding cracking along the weld overlay and base metal interface zone has been observed to occur in some cases during the vessel cool down. The tendency for dis-bonding appears to increase with increased hydrogen partial pressures and operating temperatures, as well as faster cooling during shutdown. Crack propagation occurs along the carbide precipitation zone and along the grain boundaries developed in the stainless steel/high alloy overlay near the interface with the base metal. This crack propagation in the overlay appears to be confined to a narrow region which is less than 80 per cent austenitic matrix and contains less than 15 per cent chromium. Following shutdown, calculations indicate that hydrogen tends to increase significantly and to accumulate at the transition zone. The hydrogen content at this interface increases from 30ppm at steady state conditions to around 110ppm about 12 hours after shutdown, when the vessel has cooled to ambient conditions. This occurs because hydrogen is about one order of magnitude more soluble in the weld overlay than in the base metal but its diffusivity in the weld overlay is much slower than in the base metal. Therefore, as the hydrogen diffuses from the base metal it tends to accumulate at the weld overlay interface. Under normal operating conditions, dis-bonding is not expected to occur with the vanadium modified alloys and this has also been attributed to the lower diffusivity of hydrogen in the vanadium steels caused by the hydrogen trapping effect of fine carbides. Also, weld overlay procedures have been developed and are currently used which are now more resistant to dis-bonding.

CONCLUSIONS:
Although it cannot be definitively concluded that the lack of bond was existing prior to the fabrication of the pressure vessel, because the results of the previous reports of clad plate scanning revealed no significant indication, the possibility of Hydrogen infusion during service cannot be ruled out. It could be noted that ultrasonic scanning of the pressure vessel plates for clad steel plates has been carried out in accordance with ASTM A 578 in conjunction with SA 263 or 264 or 265 which allows certain percentage of disbond between clad and base plate without any repair action. During the initial examination of the clad plates prior fabrication, it may happen that those lack of bond areas have been accepted as the total percentage of lack of bond area did not exceed beyond the acceptance limits specified by the material standard as stated above. However, the growth of the lack of bond cannot be simply neglected because of possibility of hydrogen infusion.

REFERENCES:
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3. Operational Life improvements in Modern Hydroprocessing Reactors: Liesley P Antalffy & others.
5. Casti Handbook of Cladding Technology.
6. Hydrogen Induced Cracking along the fusion boundary of Dissimilar Metal welds: M. D. Rowe & others.
8. Dis-bonding of austenitic stainless steel cladding following high temperature hydrogen service: M. F. Gittos & Others.
APPENDIX – 1

A-SCAN REPRESENTATIONS OF LACK OF BOND DURING THE MONITORING PERIOD.

DATE: 19.01.2011

DATE: 11.07.2011