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Avoid Weld Overlay Failures

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ABSTRACT

Corrosion resistant alloys (CRAs) are required for handling various corrosive fluids and process conditions in refinery and petrochemical plants. The high cost of CRA can be significantly reduced by fabricating equipment and components in dual metallurgy, especially for higher pressure / thickness applications. A lower metallurgy, carbon steel (CS) or low alloy steel (LAS), provides the required bulk pressure thickness, while the wetted surface - the surface in contact with the process fluid, is of a corrosion resistant alloy with much lesser thickness. This can be achieved by cladding, strip lining or weld overlay of the base material (CS / LAS) with CRA. Cladding or weld overlay is preferred over loose strip lining, as the CRA is well bonded to the underlying parent material.

However, proper quality assurance is critical to ensure that the CRA weld overlay functions as desired. This paper details three examples of loss of containment incidents due to weld overlay issues, emphasizing the need for proper specification and stage-wise inspection during execution.

Keywords: dilution, effective thickness, positive material identification.

INTRODUCTION

The best way to prevent internal corrosion in the process industry is to address the source – change the process fluid composition and the operating conditions. However, this may significantly alter the manufacturing process and render it unviable. This leaves two options to tackle corrosion by the process fluid: (i) use a cheaper non-resistant metallurgy with corrosion allowance, which may require periodic replacement, or (ii) use a corrosion resistant metallurgy with high initial cost. The final decision is based on total life cycle cost. In the case of corrosion resistant metallurgy, use of a clad construction further reduces the initial cost of the equipment, especially where higher pressures and thicknesses are involved.

Use of corrosion resistant metallurgy eliminates the need for additional thickness as corrosion allowance. In the case of clad construction, the cladding thickness effectively acts as the "corrosion allowance", as the lower metallurgy base material thickness takes care of internal pressure and all the other loads.

Both cladding and weld overlay provide good bonding with the base material and they are sometimes considered equivalent. However, the difference lies in one word – dilution. The clad plate has the same chemical composition across the thickness. However, the composition of the weld overlay can differ significantly from the required chemical composition across the thickness due to mixing and dilution with the molten base material.

It must be noted that even in a clad construction, weld overlay is still required at the joints, e.g. main vessel seam joints and nozzle to shell welds, and at load bearing attachment welds. These weld overlay locations can be the Achilles' heel in a cladded equipment, unless proper procedures and quality assurance are in place during fabrication.

This paper presents three loss of containment incidents that occurred due to weld overlay issues. The deficiencies observed in each case and the recommended steps to avoid recurrence are indicated.

VESSEL NOZZLE INCIDENT

Leakage was observed from an 8" nozzle of a stripper vessel within less than two months of commissioning. Puncture was observed in the nozzle just below the weld to the bottom dish end. On internal inspection, the weld overlay of SS316L was found completely damaged for about 2/3rd of the circumference in the nozzle neck. The underlying base metal was observed to be significantly corroded.

Figure 1: Failed nozzle: Left – view from Outer diameter; Right – view from Inner diameter

Pre-commissioning inspection on site had revealed poor workmanship at weld overlay locations. All three manhole covers were replaced together with localized repairs at suspect locations on nozzle welds. Complete inspection of the equipment was again carried out after the incident. Weld overlay damage was observed at the cut back areas of nozzle-shell attachment welds in nine nozzles with carbon steel base metal exposed. Corrosion grooving was observed at the nozzle-shell weld overlay in six nozzles and in the nozzle ID overlay in one nozzle.

Vessel details were as follows:

Design code	ASME Sec VIII Div-1
Shell MOC	SA 516 Gr 70N + 3 mm SS316L cladding
Shell thickness	10 mm CS + 3mm SS 316 L cladding

As per the project design basis, nozzle sizes up to 4” shall be solid austenitic stainless steel and for nozzle sizes >=6”, nozzle neck shall be carbon steel with stainless steel cladding / weld overlay. Vendor had followed this criteria - nozzles of 6” and 8” were provided with weld overlay on nozzle neck; nozzle necks 12” and above were fabricated from explosion clad plate.

Visual inspection and DPT at the shell to top and bottom dish end joints revealed pits in the weld overlay. Weld overlay corrosion was also observed along the circumferential weld.

Figure 2: Pits in the circumferential seam weld overlay

WHAT WENT WRONG

Vessel cladding was unaffected. Welds in the connected piping to the vessel of the same SS316L metallurgy were internally inspected after the incident and found intact. Discoloration and rusting of the vessel overlay welds at a number of locations indicated corrosion due to inadequate weld composition.

The equipment drawing clearly stated the requirement for minimum 5 mm SS316L weld overlay to achieve min. 3 mm undiluted chemistry for nozzle neck / flange overlay, overlay at nozzle attachment cutback areas and main seam welds. However based on a later investigation, this requirement had been followed only for the overlay weld procedure qualification.

As per the procedure qualification record, total weld deposited was 7 mm in four layers. Positive Material Identification (PMI) was then carried out after grinding down to 3 mm remaining thickness and found acceptable. The welding procedure specification stated that 3 mm and above weld metal thickness was qualified. The actual overlay was flush with the 3 mm clad thickness or had reduced below the clad thickness after weld grinding and machining to achieve the local profile / dimensions. There was no recess provided in the base metal to accommodate higher overlay thickness.

The approved Inspection and Test Plan (ITP) included 100% Penetrant Testing (PT) of the 1st run and finish run of weld overlay. PMI of all SS components, including welds, was mentioned as a note in the inspection and test plan, not as an inspection activity. Hence no PMI report was submitted as part of the Manufacturing Record Book (MRB). Based on internal visual inspection as well as the defects observed during commissioning inspection and after the current failure, these requirements were not consistently followed by the vendor.

EXCHANGER CHANNEL COVER FLANGE INCIDENT

Leakage was observed from the body of the bottom channel girth flange (Figure 3) of a column re-boiler during normal plant operation. The new exchanger had been in service for less than nine months. The exchanger details were as follows:

	Shell	Tubes
Material of construction	Carbon steel - SA 516 Gr. 70	Titanium – SB338 Gr. 2
Fluid service	Steam	Acid + water

The tube-sheet metallurgy was titanium-clad carbon steel. End covers were of solid duplex (SS2205) metallurgy, while the weld neck flanges were carbon steel with duplex liner on the flange face and duplex weld overlay on the flange inner diameter.

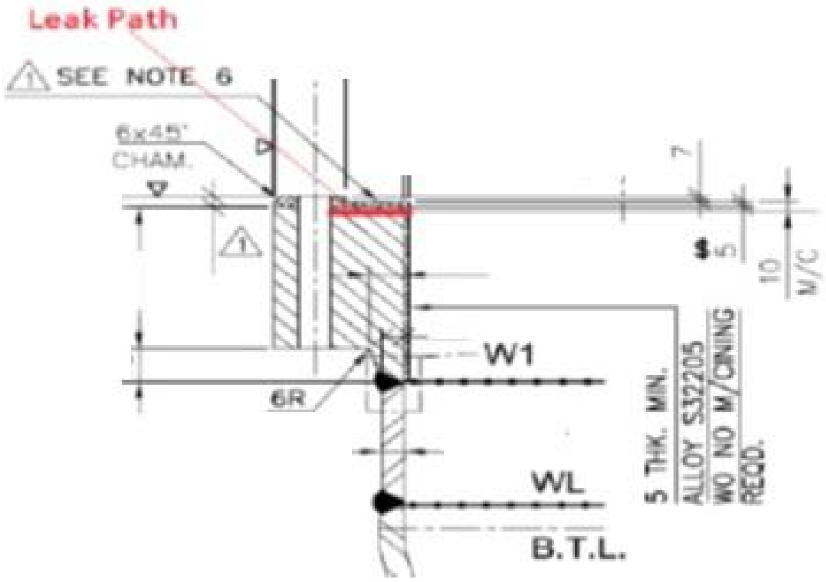

Figure 3: Extract from exchanger drawing indicating the leak path (in red)

Internal inspection, after dropping the end cover, revealed corrosion damage in the weld overlay area at number of locations around the inner circumference of the channel cover just below the flange face. Corrosion had created a gap in the overlay at the leak location. Grinding of the overlay in this area revealed extensive metal loss of the underlying parent material (Figure 4). The affected area was repaired by weld build-up and duplex overlay as an immediate measure. The channel flanges were then replaced with solid duplex (SS2205) flanges at the next opportunity.

WHAT WENT WRONG

Longitudinal and circumferential seam welds in the solid duplex shell and dome of the channel cover were not affected. Similarly welds in the connected duplex piping to the vessel were inspected after failure and found intact. However the duplex weld overlay on the channel flange inner diameter, just below the gasket seating face, showed discoloration and corrosion. This clearly indicated inadequate weld chemical composition.

The exchanger drawing (Figure 3) clearly indicated minimum 5 mm thick duplex (SS2205) weld overlay on the inner diameter of the channel cover flange. The exchanger manufacturer may have complied with this requirement during fabrication of the channel cover.

However the inner diameter of the channel cover flange was later machined to enable final assembly with the mating tube-sheet flange on the shell / exchanger body. This machining was done without any reference to the client or the third party inspection agency. This significantly reduced the overlay thickness and brought the diluted weld composition in contact with the process fluid.

Figure 4: Extent of metal loss in the underlying base material under the overlay

COLUMN BLIND FLANGE INCIDENT

Acid fumes were noticed from the nozzle end blind (2” 300#) of a column during normal operation. The end blind was found holed through in the central portion. Material of construction of the failed end blind was carbon steel (CS) with monel weld overlay up to the gasket seating area. The column metallurgy was solid monel and the man-way covers were carbon steel (CS) with 3 mm monel overlay, as per the equipment drawing.

Figure 5: Failed end blind – External surface (left); internal surface (right)

This 2" drain nozzle had connected piping as per the original design and was used during unit start-up and shutdown. However the connected piping was later removed through management of change (MOC) process and the subject end blind was provided at this nozzle.

WHAT WENT WRONG

The end blind weld overlay was analyzed after the failure. The thickness of the weld overlay was found to be 1.6 to 1.9 mm instead of 3 mm (Overlay thickness at other locations as per drawing). The surface overlay weld composition was found to be significantly diluted with up to 24% iron (Fe). Comparison of the required monel composition with actual composition of the weld overlay is given below.

Element	Nickel	Copper	Iron	Manganese	Carbon
Required (%)	63.0 min.	28.0 – 34.0	2.50 max.	2.0 max.	0.3 max.
Actual (%)	48.4	22.5	24.0	3.0	0.064

This end blind was never opened during periodic internal inspection of the column. All nozzles are customarily blinded / spaded for vessel entry during such inspections, as a safety requirement. Hence the overlay damage went un-noticed until failure.

RECOMMENDATIONS TO AVOID RECURRENCE

The following recommendations were put in place to avoid recurrence of such incidents:

- The number of layers and layer thickness in production weld overlay shall not be less than the number of layers and layer thickness deposited for procedure qualification.
- Total weld overlay thickness shall be selected such that undiluted chemistry is achieved at minimum 3 mm depth from the final (machined) weld overlay surface. Hence the minimum total thickness of weld overlay shall be 5 mm or higher, as required to achieve the required undiluted thickness.
  - The total overlay thickness shall take into account all machining / dimensional steps required, including machining for ease of assembly, so that the minimum required undiluted depth is achieved even at the least thickness location after machining. Finish machining SHALL NOT penetrate into the diluted layer.
  - Machining of grooves in the base material is permissible to meet the undiluted overlay thickness requirement, provided the residual thickness of the base material is not less than the required design thickness.
  - Weld overlay thickness shall be verified by actual measurement at the exposed edge, if available. Alternately overlay thickness shall be verified by ultrasonic thickness measurement of the base material before and after overlay. Post –overlay thickness measurement shall be carried out after machining to final dimensions.
  - The chemical composition shall be checked by Positive Material Identification (PMI) by grinding sample spots to the required undiluted depth on the final production weld overlay. Such testing and re-instatement of overlay thickness shall be conducted before post weld heat treatment (PWHT), if applicable.

CONCLUSIONS

Use of a corrosion resistant metallurgy during initial project procurement or asset renewal should minimize the in-service inspection requirements and eliminate corrosion-related repairs / replacement during plant operation. But this can be achieved only if the necessary care is taken during specification, design, fabrication, stage-wise inspection and installation.

The paper has highlighted three incidents to emphasize the need for proper specification and execution of weld overlays. Corrosion-resistant cladding and weld overlay is expected to effectively act as the barrier to process fluid corrosion over the design life of the equipment or asset. To achieve this, the final undiluted thickness of the weld overlay shall be at least equal to the clad thickness. This must be ensured not only during the weld overlay procedure qualification but also during fabrication

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REFERENCES